



# **Declaration**

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Santoso Wibowo

31<sup>st</sup> January 2011

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# Abstract

Multicriteria decision making refers to selecting or ranking alternatives from available alternatives with respect to multiple, usually conflicting criteria involving either a single decision maker or multiple decision makers. It often takes place in an environment where the information available is uncertain, subjective and imprecise. To adequately solve this decision problem, the application of fuzzy sets theory for adequately modelling the subjectiveness and imprecision in multicriteria decision making has proven to be effective.

Much research has been done on the development of various fuzzy multicriteria analysis approaches for effectively solving the multicriteria decision making problem, and numerous applications have been reported in the literature. In general, existing approaches can be categorized into (a) multicriteria decision making with a single decision maker and (b) multicriteria group decision making. Existing approaches, however, are not totally satisfactory due to various shortcomings that they suffer from including (a) the inability to adequately model the subjectiveness and imprecision of human decision making, (b) the failure to effectively handle the requirements of decision maker(s), (c) the tedious mathematical computation required, and (d) cognitively very demanding on the decision maker(s).

This research has developed four novel approaches for effectively solving the multicriteria decision making problem under uncertainty. To effectively reduce the cognitive demand on the decision maker, a pairwise comparison based approach is developed in Chapter 4 for solving the multicriteria problem under uncertainty. To adequately meet the interest of

various stakeholders in the multicriteria decision making process, a decision support system (DSS) based approach is introduced in Chapter 5. In Chapter 6, a consensus oriented approach is presented in multicriteria group decision making on which a DSS is proposed for facilitating consensus building in solving the multicriteria group decision making problem. In Chapter 7, a risk-oriented approach is developed for adequately modelling the inherent risk in multicriteria group decision making with the use of the concept of ideal solutions so that the complex and unreliable process of comparing fuzzy utilities usually required in fuzzy multicriteria analysis is avoided.

Empirical studies of four real fuzzy multicriteria decision making problems are presented for illustrating the applicability of the approaches developed in solving the multicriteria decision making problem. A hospital location selection problem is discussed in Chapter 8. An international distribution centre location problem is illustrated in Chapter 9. A supplier selection problem is presented in Chapter 10. A hotel location problem is discussed in Chapter 11. These studies have shown the distinct advantages of the approaches developed respectively in this research from different perspectives in solving the multicriteria decision making problem.

# Table of Contents

<b>Declaration</b> .....	i
<b>Acknowledgement</b> .....	ii
<b>Abstract</b> .....	iii
<b>List of Publications</b> .....	x
<b>List of Tables</b> .....	xii
<b>List of Figures</b> .....	xv

## **Chapter 1 Introduction**

1.1 Background .....	1
1.2 Problem Statement .....	5
1.3 Objectives of the Research .....	7
1.4 Outline of the Research .....	9

## **Chapter 2 A Review of Fuzzy Multicriteria Analysis Approaches**

2.1 Introduction .....	13
2.2 Multicriteria Decision Making With A Single Decision Maker .....	14
2.2.1 Utility Based Approaches .....	15
2.2.2 Mathematical Programming Approaches .....	23
2.2.3 Pairwise Comparison Based Approaches .....	27
2.2.4 Outranking Approaches .....	32
2.3 Multicriteria Group Decision Making .....	38

2.3.1 Majority Based Approaches .....	38
2.3.2 Ranking Based Approaches.....	41
2.3.3 Consensus Based Approaches .....	45
2.4 Concluding Remarks .....	51

### **Chapter 3 Problem Formulation and Developments**

3.1 Introduction .....	52
3.2 The Fuzzy Multicriteria Decision Making Problem.....	54
3.3 Decision Contexts and Challenges .....	56
3.3.1 Decision Context A .....	57
3.1.1 Decision Context A .....	57
3.3.1.2 Challenges for Decision Context A.....	57
3.3.2 Decision Context B .....	58
3.3.2.1 Decision Context B .....	58
3.3.2.2 Challenges for Decision Context B .....	58
3.3.3 Decision Context C .....	58
3.3.3.1 Decision Context C .....	58
3.3.3.2 Challenges for Decision Context C .....	58
3.3.4 Decision Context D .....	59
3.3.4.1 Decision Context D .....	59
3.3.4.2 Challenges for Decision Context D .....	59
3.4 An Overview of the Developments .....	59
3.5 Concluding Remarks .....	62

## **Chapter 4 Pairwise Comparison Based Multicriteria Decision Making under Uncertainty**

4.1	Introduction .....	63
4.2	Some Preliminary Concepts .....	64
4.2.1	Fuzzy Sets.....	64
4.2.2	Fuzzy Numbers.....	65
4.2.3	Arithmetic Operations on Fuzzy Numbers.....	65
4.2.4	Fuzzy Synthetic Extent Analysis.....	67
4.3	A Pairwise Comparison Based Approach .....	68
4.4	Concluding Remarks .....	74

## **Chapter 5 Effective Decision Support for Fuzzy Multicriteria Group Decision Making**

5.1	Introduction .....	75
5.2	A Fuzzy Multicriteria Group Decision Making Algorithm.....	77
5.3	A Multicriteria Decision Support System .....	83
5.4	Concluding Remarks .....	86

## **Chapter 6 A Consensus Based Approach for Multicriteria Group Decision Making**

6.1	Introduction .....	88
6.2	Consensus Building in Group Decision Making .....	89
6.3	A Consensus Building Algorithm .....	92
6.4	A Decision Support System .....	99
6.5	Concluding Remarks .....	101



## **Chapter 7 Risk-Oriented Decision Making for Multicriteria Group Decision Making under Uncertainty**

7.1	Introduction .....	102
7.2	A Risk-Oriented Approach.....	103
7.3	Concluding Remarks .....	110

## **Chapter 8 Hospital Location Evaluation and Selection under Uncertainty**

8.1	Introduction .....	112
8.2	The Hospital Location Evaluation and Selection .....	113
8.3	Data Collection.....	117
8.4	Results and Discussion.....	122
8.5	Concluding Remarks .....	125

## **Chapter 9 A Decision Support System Approach for Selecting International Distribution Centres under Uncertainty**

9.1	Introduction .....	126
9.2	The International Distribution Centre Evaluation and Selection .....	128
9.3	Data Collection.....	132
9.4	Results and Discussion.....	135
9.5	Concluding Remarks .....	143

## **Chapter 10 Consensus Based Supplier Evaluation and Selection**

10.1	Introduction .....	144
10.2	Suppliers Evaluation and Selection in Taiwan.....	145
10.3	Data Collection.....	149

10.4 Results and Discussion .....	152
10.5 Concluding Remarks .....	158

## **Chapter 11 A Risk-Oriented Approach for Evaluating and Selecting Hotel Locations under Uncertainty**

11.1 Introduction .....	160
11.2 The Hotel Location Evaluation and Selection.....	162
11.3 Data Collection.....	166
11.4 Results and Discussion .....	169
11.5 Concluding Remarks .....	174

## **Chapter 12 Conclusion**

12.1 Introduction .....	176
12.2 Characteristics of the Approaches Developed.....	177
12.3 Implications of the Empirical Studies .....	180
12.4 Contributions of the Research .....	183
12.5 Suggestions for Future Research.....	185

<b>References.....</b>	<b>187</b>
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<b>Appendix A: List of Abbreviations.....</b>	<b>216</b>
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# List of Publications

## Refereed Journal Papers

Yeh C. H., Deng, H., Wibowo, S., and Xu, Y., 2010. Multicriteria Group Decision for Information Systems Project Selection under Uncertainty, *International Journal of Fuzzy Systems*, Volume 12, Issue 2, Pages 170-179.

Wibowo, S., and Deng, H., 2009. A Consensus Support System for Supplier Selection in Group Decision Making, *Journal of Management Science and Statistical Decision*, Volume 6, Issue 4, Pages 52-59.

## Book Chapter

Yeh, C. H., Deng, H., and Wibowo, S., 2009. Multicriteria Group Decision Support for Information Systems Project Selection, *Industrial, Engineering and Other Applications of Applied Intelligent Systems*, IEA-AIE 2009, Tainan, Taiwan, Proceedings, *Lecture Notes in Artificial Intelligence*, Volume 5579, Springer-Verlag, Berlin, Heidelberg, Pages 152-161.

## Refereed Conference Publications

Wibowo, S., and Deng, H., 2011. Intelligent Decision Support for Criteria Weighting in Multicriteria Analysis for Evaluating and Selecting Cargo Ships under Uncertainty, *Proceedings of the 2011 IAENG International Conference on Operations Research*, 16 February - 19 February, Hong Kong.

Wibowo, S., and Deng, H., 2010. Risk-Oriented Group Decision Making in Multi-Criteria Analysis, *Proceedings of the 9th IEEE/ACIS International Conference on Computer and Information Science (ICIS 2010)*, 18 August - 20 August, Yamagata, Japan.

Wibowo, S., and Deng, H., 2010. A Fuzzy Screening System for Effectively Solving Maritime Shipping Problem, *Proceedings of the 25th Mini-EURO Conference Uncertainty and Robustness in Planning and Decision Making (URPDM 2010)*, 15 April - 17 April, Coimbra, Portugal.

Wibowo, S., and Deng, H., 2009. Consensus-Based Decision Support for Supplier Selection in Multi-criteria Group Decision Making, *Proceedings of the 10<sup>th</sup> International Conference on Intelligent Technologies*, 12 December - 15 December, Guilin, China.

Deng, H., and Wibowo, S., 2009. Fuzzy Multicriteria Analysis for Selecting Information Systems Project, *Proceedings of the IEEE International Conference on Fuzzy Systems and Knowledge Discovery*, 14 August - 16 August, Tianjin, China.

## List of Tables

Table 3.1	Linguistic Terms for Representing Two Linguistic Variables: Capability and Importance .....	56
Table 4.1	Linguistic Variables and Their Fuzzy Number Approximations for Making Pairwise Comparison Assessments .....	66
Table 8.1	A Fuzzy Reciprocal Judgment Matrix for the Financial Attractiveness Criterion .....	118
Table 8.2	A Fuzzy Reciprocal Judgment Matrix for the Demand Potential Criterion .....	119
Table 8.3	A Fuzzy Reciprocal Judgment Matrix for the Organizational Strategy Criterion .....	119
Table 8.4	A Fuzzy Reciprocal Judgment Matrix for the Supporting Industries Criterion .....	120
Table 8.5	A Fuzzy Reciprocal Judgment Matrix for the Government Influence Criterion .....	120
Table 8.6	A Fuzzy Reciprocal Judgment Matrix for the Marketing Dynamics Criterion .....	121
Table 8.7	A Fuzzy Reciprocal Judgment Matrix for the Relative Importance of the Selection Criteria.....	121
Table 8.8	The Decision Matrix for the Hospital Location Selection Problem.....	123
Table 8.9	The Weighted Fuzzy Performance Matrix for the Hospital Location Selection Problem .....	123
Table 8.10	The Overall Performance Index and Ranking of Hospital Location Alternatives .....	124

Table 9.1	Performance Assessments of International Distribution Centre Alternatives ....	134
Table 9.2	Criteria Weights for International Distribution Centre Alternatives .....	135
Table 9.3	The Overall Fuzzy Decision Matrix and the Overall Fuzzy Weight Vector of International Distribution Centre Alternatives .....	137
Table 9.4	The Weighted Fuzzy Performance Matrix of International Distribution Centre Alternatives .....	138
Table 9.5	The Fuzzy Maximum and the Fuzzy Minimum.....	139
Table 9.6	The Degree of Dominance Across International Distribution Centre Alternatives .....	140
Table 9.7	The Degree of Dominance for International Distribution Centre Alternatives .....	141
Table 9.8	The Overall Performance Index and Ranking of International Distribution Centre Alternatives .....	142
Table 10.1	Performance Assessments of Alternative Suppliers and Criteria Weights .....	151
Table 10.2	The Degree of Similarity of Decision Makers .....	154
Table 10.3	The Consistency Index of Individual Decision Makers.....	155
Table 10.4	The Weighted Fuzzy Performance Matrix of Suppliers .....	156
Table 10.5	The Hamming Distance Between Each Supplier Alternative and the Ideal Solutions.....	157
Table 10.6	The Overall Performance Index and Ranking of Suppliers .....	157
Table 11.1	Performance Assessments of Hotel Location Alternatives.....	168
Table 11.2	Weighting Vectors for the Criteria.....	168
Table 11.3	The Weighted Fuzzy Performance Matrix of Hotel Location Alternatives.....	170
Table 11.4	The Fuzzy Performance Matrix for Individual Decision Makers .....	171
Table 11.5	The Overall Fuzzy Decision Matrix of Hotel Location Alternatives.....	172

Table 11.6 The Hamming Distance Between Each Alternative and the Ideal Solutions..... 172

Table 11.7 The Overall Performance Index and Ranking of Hotel Location

Alternatives ..... 173

## List of Figures

Figure 1.1 The Research Framework .....	9
Figure 3.1 An Overview of the Developments.....	60
Figure 5.1 The Decision Support System Framework for Multicriteria Group Decision Making .....	86
Figure 6.1 The Decision Support System Framework .....	100
Figure 8.1 The Hierarchical Structure of the Hospital Location Evaluation and Selection Problem .....	115
Figure 9.1 The Hierarchical Structure for International Distribution Centre Evaluation and Selection .....	131
Figure 10.1 The Hierarchical Structure of the Supplier Evaluation and Selection Problem .....	147
Figure 11.1 The Hierarchical Structure for Hotel Location Evaluation and Selection .....	165



# Chapter 1

## Introduction

### 1.1 Background

Decision making is an important activity that occurs frequently in everyday human functioning. It usually consists of finding the best alternative from available alternatives in a given situation (Hwang and Yoon, 1981; Chen and Hwang, 1992; Turban et al., 2008). Decision making has received a great deal of interest from researchers and practitioners in many disciplines including psychology, sociology, political science, economics, applied mathematics, engineering, computer science and artificial intelligence (Raiffa, 1997; Triantaphyllou, 2000; Belton and Stewart, 2002; Peterson, 2009). This is because effective and efficient decision making can substantially determine the profitability and even survival of individual organizations and directly improve the quality of human lives.

Decision making problems are usually different with respect to the nature of the problem, the size of the problem, the time available for making the decision, and the presence of subjectiveness and imprecision in the human decision making process (Hwang and Yoon, 1981; Chen and Hwang, 1992; Yoon and Hwang, 1995; Deng and Wibowo, 2008). Effective and consistent decision making in a given situation requires the decision maker(s) to adequately consider all these specific characteristics of the decision problem in a real world setting.

Decision making problems in the real world are usually multi-dimensional (Zopounidis and Doumpos, 2002; Ölçer and Odabasi, 2005; Deng, 2009). This is due to the presence of multiple, often conflicting objectives including economic, environmental, societal, and technical ones (Yoon and Hwang, 1995; Ganoulis, 2003; Hu et al., 2007). Such objectives are usually a reflection of the interest of various stakeholders in the decision making process. To effectively solve the decision making problem, the decision making process cannot be reduced to the problem of a single objective such as the pursuit of maximum economic efficiency. Effective decision making requires the consideration of all associated objectives simultaneously (Chen and Hwang, 1992; Deng and Yeh, 1997; Deng and Yeh, 2006).

The size of the problem is another source of complexity in the decision making process (Deng, 2009). It directly determine the amount of information that the decision maker needs to handle in the decision making process. For a decision problem of a large size, the decision maker is often faced with a heavy cognitive burden due to the limitation of individual decision makers on the amount of information that they can effectively handle (Miller, 1956).

The time available for making the decision is another issue of concern in the decision making process (Chen et al., 2008). In practical situations, decision makers are often faced with the pressure for making the decision with the limited time available. Numerous studies have found that the time available for making decisions affects the quality of the decision outcome (Ben Zur and Breznitz, 1981; Cohen et al., 1996; Kocher and Sutter, 2006). As a result, how to adequately consider the time available for making effective decisions is critical.

Subjectiveness and imprecision are always present in the human decision making process (Deng and Wibowo, 2004; Kahraman, 2008). Their existence is often due to the presence of

(a) incomplete information, (b) abundant information, (c) conflicting evidence, (d) ambiguous information, and (e) subjective information in the decision making process (Chen and Hwang, 1992; Zimmermann, 2000; Deng and Yeh, 2006). Adequately modelling the subjectiveness and imprecision in the human decision making process becomes a critical issue for an effective decision making (Stamelos and Tsoukias, 2003; Deng and Wibowo, 2008).

To effectively solve the decision making problem described as above, multicriteria decision making is widely used (Fenton and Wang, 2006; Lin et al., 2007; Yeh and Chang, 2009). Generally speaking, multicriteria decision making refers to select or rank alternatives from available alternatives with respect to multiple, usually conflicting criteria involving either a single decision maker or multiple decision makers (Chen and Hwang, 1992; Easley et al., 2000; Kuo et al., 2006; Yeh et al., 2010). Multicriteria decision making problems are common in everyday lives. For example, a customer wants to select a car which requires the consideration of the fuel economy, the reliability, and the style of the available cars. An organization needs to select an information system project for development with respect to the project economy, the risk, and the technical capability of available projects.

In general, multicriteria decision making can be classified as (a) multiattribute decision making and (b) multiobjective decision making (Hwang and Yoon, 1981; Yoon and Hwang, 1995; Ribeiro, 1996; Kahraman, 2008). Multiattribute decision making is the most well-known branch of decision making (Kahraman, 2008). Multiattribute decision making problems are assumed to have a predetermined, limited number of decision alternatives. Multiattribute decision making involves in the evaluation, selection and ranking of alternatives from available alternatives with respect to various criteria (Ribeiro, 1996).

Commonly used approaches for solving this kind of decision problems include the simple additive weighting (SAW) approach (Hwang and Yoon, 1981; Vincke, 1992; Olson, 1996), the analytic hierarchy process (AHP) (Saaty, 1980), the elimination and et choice translating reality (ELECTRE) approach (Roy, 1996; Figueira et al., 2005), and the technique for order preference by similarity to ideal solution (TOPSIS) (Chen and Hwang, 1992; Triantaphyllou and Sanchez, 1997; Zanakis et al., 1998; Gal et al., 1999; Triantaphyllou, 2000).

Multiobjective decision making involves in the selection of the satisfactory alternative from among a set of alternatives based on the preference information of the decision maker in relation to the priorities of the evaluation criteria and objectives and the relationships between the objectives and criteria in consideration (Iz and Jelassi, 1990; Quaddus and Siddique, 1996). Existing approaches for solving this kind of decision problems include integer programming approach (Zimmermann, 1987), zero-one mathematical programming approach (Santhanam et al., 1989), non-linear zero-one mathematical programming approach (Chen and Hwang, 1992), and goal programming approach (Badri et al., 2001).

Most decisions made in the real world take place in an environment in which the goals and constraints are not known precisely (Bellman and Zadeh, 1970). As a result, the problem cannot be exactly defined or precisely represented in a crisp manner (Zimmermann, 2000; Cakir and Canbolat, 2008). Attempts to handle this uncertainty, imprecision and subjectiveness inherent in the human decision making process are carried out basically along the lines of probability theory (Dubois and Prade, 1994; Yeh et al., 1999) and fuzzy sets theory (Zadeh, 1965; Zimmermann, 2000). The probability theory focuses on the stochastic nature of the decision making process while the fuzzy sets theory concerns about the subjectiveness and imprecision of the human behaviour (Yeh et al., 1999; Deng, 2005).

Stochastic approaches such as statistical analysis are found to be inadequate in handling the subjectiveness and imprecision of the human decision making process (Deng, 2005; Xu, 2007; Deng and Molla, 2008). To effectively represent the subjective and imprecise information inherent in the multicriteria decision making problem, the application of fuzzy sets theory (Bellman and Zadeh, 1970) for adequately modelling the subjectiveness and imprecision has proven to be effective, leading to the development of fuzzy multicriteria analysis approaches for solving the multicriteria decision making problem in a fuzzy environment (Ribeiro, 1996; Zimmermann, 2000; Deng and Yeh, 2006; Chou and Chang, 2008; Yu et al., 2009).

## 1.2 Problem Statement

The problem of interest in this study is the general fuzzy multicriteria decision making problem. Such a problem is mainly concerned about evaluating and selecting alternatives from a set of available alternatives with respect to multiple, usually conflicting criteria involving a single decision maker or multiple decision makers. The evaluation and selection of alternatives usually involves in the following five steps: (a) identifying the available alternatives as decision alternatives  $A_i$  ( $i = 1, 2, \dots, n$ ), (b) determining the evaluation criteria  $C_j$  ( $j = 1, 2, \dots, m$ ), (c) assessing the performance ratings of alternatives with respect to each criterion and the relative importance of the criteria by a single decision maker  $D_k$  ( $k = 1$ ) or through a certain level of agreement by multiple decision makers  $D_k$  ( $k = 1, 2, \dots, s$ ), (d) aggregating the alternatives' performance ratings and criteria weights for producing an overall performance index for each alternative across all criteria, and (e) selecting the most suitable alternative.

Mathematically, the general multicriteria decision making problem can be formulated as follows:

$$\text{Max} \quad f_i(u), \quad i = 1, 2, \dots, k, \quad (1.1)$$

$$\text{Subject to: } g_j(u) \leq 0, j = 1, 2, \dots, n,$$

where  $u$  is a  $m$  dimensional decision variable vector. The problem consists of  $m$  decision variable,  $n$  constraints and  $k$  objectives (Hwang and Masud, 1979).

Two common approaches are available for addressing this decision problem (Hwang and Masud, 1979; Hwang and Yoon, 1981; Chen and Hwang, 1992). One is to optimize one of the objectives while appending the other objectives to a constraint set so that an optimal solution would satisfy these objectives at least up to a predetermined level. Following this idea, the general multicriteria decision making problem can be formulated as:

$$\text{Max} \quad f_i(u), \quad i = 1, 2, \dots, k, \quad (1.2)$$

$$\text{Subject to: } g_j(u) \leq 0, \quad j = 1, 2, \dots, n,$$

$$f_i(u) \geq a_h, \quad h = 1, 2, \dots, k, h \neq i,$$

where  $a_h$  is any acceptable predetermined threshold value for objective  $h$ .

The other approach is to optimize a super-objective function created by multiplying each objective function by an appropriate weight coefficient before adding them together along the line of the utility theory (Hwang and Yoon, 1981; Olson, 1996; Deng, 1999). With this approach, the decision problem can be formulated as follows:

$$\text{Max} \quad \sum_{i=1}^n w_i f_i(u), \quad (1.3)$$

$$\text{Subject to: } g_j(u) \leq 0, \quad i = 1, 2, \dots, n,$$

This research takes the second approach for tackling the general multicriteria decision making problem under uncertainty. The underlying assumption of this approach is that the fuzzy set theory (Bellman and Zadeh, 1970) is more appropriate and effective as compared to the traditional mathematical theory for dealing with the subjectiveness and imprecision of the human decision making process in multicriteria decision making (Carlsson, 1982; Chen and Hwang, 1992; Zimmermann, 1996; Deng, 2005).

### **1.3 Objectives of the Research**

Much research has been done on the development of numerous fuzzy multicriteria analysis approaches for solving various practical problems (Bellman and Zadeh, 1970; Dubois and Prade, 1980; Hwang and Yoon, 1981; Zimmermann, 1987; Chen and Hwang, 1992; Ribeiro, 1996; Wang and Parkan, 2005; Gu and Zhu, 2006). These approaches are developed from various perspectives for helping the decision maker deal with the fuzzy multicriteria decision making problem with respect to special circumstances in the real world setting. Numerous applications of the approaches developed for addressing real world fuzzy multicriteria decision making problems have been reported in the literature. These applications include portfolio management (Muralidhar et al., 1990; Stamelos and Tsoukias, 2003), supplier selection (Chen et al., 2006; Araz and Ozkarahan, 2007), information systems allocation (Santhanam and Kyparisis, 1995; Badri et al., 2001; Lee and Kim, 2001), and location planning (Kahraman et al., 2003; Chou et al., 2008).

Despite tremendous efforts have been spent and significant advances have been made towards the development of various fuzzy multicriteria analysis approaches for solving

various multicriteria decision making problems, there is no best approach available for solving the general multicriteria decision making problem. Most existing approaches suffer from various shortcomings including (a) the failure to adequately handle the subjectiveness and imprecision inherent in the decision making process (Deng and Wibowo, 2008), (b) the requirement of complicated mathematical computation (Deng, 1999), and (c) the failure to adequately handle the various requirements of the decision maker(s) (Yeh et al., 2000). In particular, existing approaches often ignore the requirements of individual decision maker(s) while requiring rigorous assumptions (Wibowo and Deng, 2011). This is impractical, as decision problems vary greatly in real situations (Chiclana et al., 2007; Deng and Wibowo, 2008; Yu et al., 2009). It is obvious that the development of simple, comprehensible and efficient approaches, which are capable of addressing individual requirements of specific multicriteria decision making problems, is desirable.

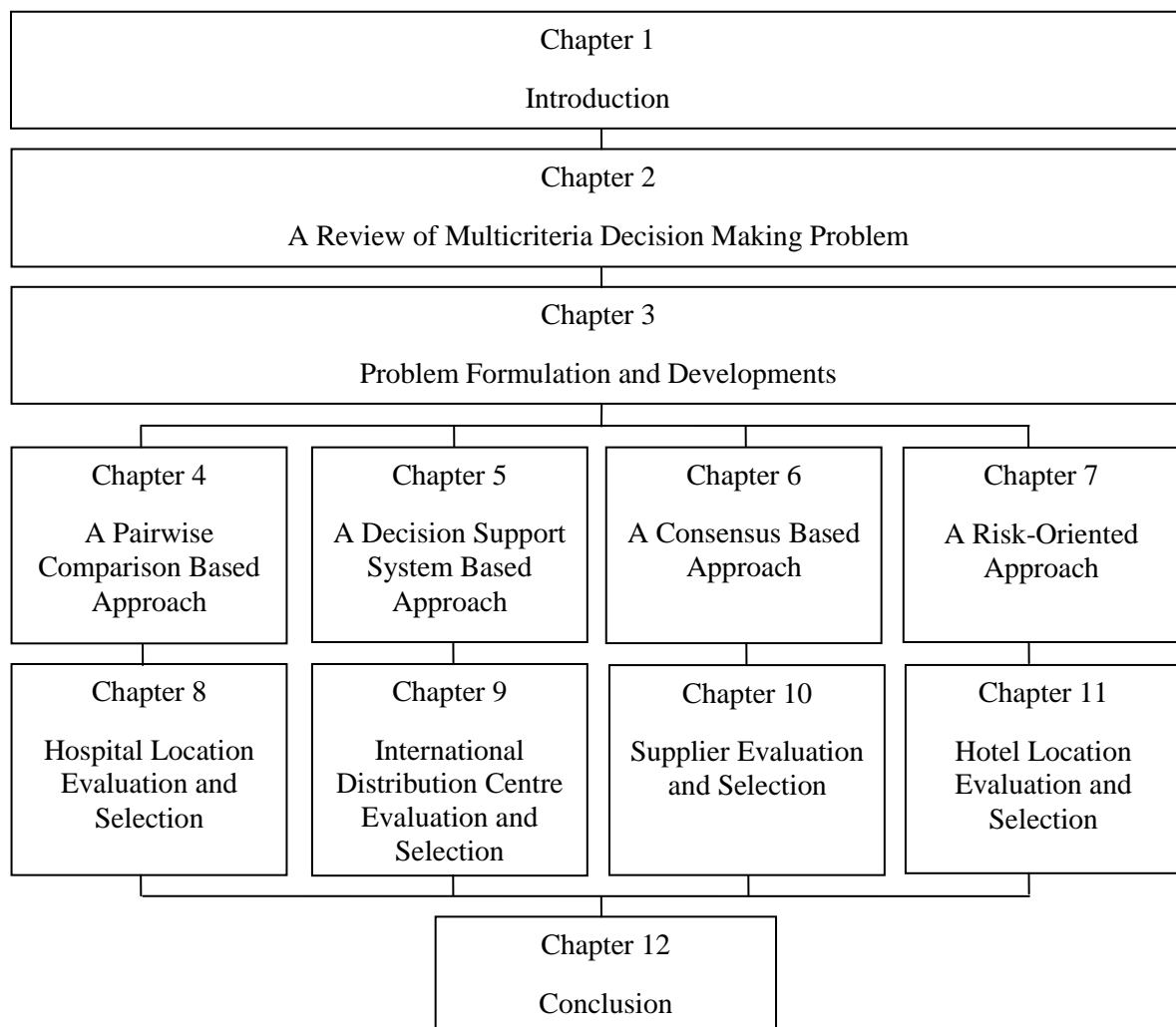
In order to address the challenges described as above, this research aims to develop novel approaches capable for effectively solving the general fuzzy multicriteria decision making problem in a simple and straightforward manner. More specifically, this research will:

- (a) Conduct a comprehensive review of existing fuzzy multicriteria analysis approaches for dealing with the general fuzzy multicriteria decision making problem;
- (b) Develop novel approaches for solving the multicriteria decision making problem in a fuzzy environment; and
- (c) Demonstrate the applicability of the developments as above for solving the real world multicriteria decision making problem through the empirical studies.



## 1.4 Outline of the Research

Figure 1.1 shows the organization of the thesis in this study. It provides an overview of the whole research with the relationship between the methodology developments and their corresponding applications in the general multicriteria decision making setting. As shown in Figure 1.1, Chapter 1 provides a brief introduction to the general multicriteria decision making problem with the description of the research objectives. This sets up the foundation for the whole study in this thesis.



**Figure 1.1 The Research Framework**

Chapter 2 provides a comprehensive review of existing approaches for solving the fuzzy multicriteria decision making problem. This literature review is organized from the perspectives of (a) multicriteria decision making with a single decision maker and (b) multicriteria group decision making. To justify the need for the developments of novel approaches for effectively addressing the multicriteria decision making problem, the chapter has highlighted the major drawbacks of existing approaches for solving the general multicriteria decision making problem.

Chapter 3 formulates the general fuzzy multicriteria decision making problem for facilitating the methodology development. Several special decision contexts in fuzzy multicriteria decision making are identified. Justifications are present on the need for the development of novel approaches in effectively solving the fuzzy multicriteria decision making problem.

To effectively reduce the cognitive demand on the decision maker, a pairwise comparison based approach for adequately solving the multicriteria decision making problem under uncertainty is developed in Chapter 4. As a result, effective decisions can be made due to the great reduction of the cognitive demanding on the decision maker and the adequate modelling of the subjectiveness and imprecision in the decision making process.

To adequately meet the interest of various stakeholders in multicriteria decision making, a decision support system (DSS) based approach is introduced in Chapter 5 for effectively solving the multicriteria group decision making problem. To avoid the complex and unreliable process of comparing fuzzy numbers usually required in fuzzy multicriteria analysis (Shih et al., 2005), a new algorithm is developed based on the degree of dominance

(Deng, 1999) and the degree of optimality (Yeh et al., 2000). A DSS is introduced to facilitate the multicriteria group decision making process efficiently and effectively.

To effectively improve the acceptance of the decision made by multiple decision makers, Chapter 6 develops a consensus based approach for multicriteria group decision making. To facilitate its use in solving real world decision making problems, a DSS is proposed incorporating the proposed consensus building algorithm for facilitating the consensus building process in solving the multicriteria group decision making problem.

To effectively explore the risk inherent in the multicriteria decision making process, Chapter 7 presents a risk-oriented approach for multicriteria group decision making. The concept of ideal solutions is applied for calculating the overall performance index for each alternative across all criteria so that the complex and unreliable process of comparing fuzzy utilities often required in fuzzy multicriteria decision making is avoided.

To demonstrate the applicability of the approaches developed for solving real world decision problems, Chapters 8 to 11 present empirical studies of four real fuzzy multicriteria decision making problems with the use of the novel approaches developed in Chapters 4 to 7 respectively. The real multicriteria decision making situations are described, and the need for adopting a specific multicriteria decision making approach in solving a specific multicriteria decision making problem is justified. These studies have shown the distinct advantages of the approaches developed respectively in this research from different perspectives in solving the multicriteria decision making problem.

Chapter 12 provides a summary of the developments and their applications for solving real world decision problems. The contributions of this research are restated, and the future research is discussed.

## Chapter 2

# A Review of Multicriteria Analysis Approaches

### 2.1 Introduction

Effectively solving the multicriteria decision making problem is complex and challenging. The complexity of the multicriteria decision making process is due to the multi-dimensional nature of the decision making process (Deng and Wibowo, 2004), the conflicting nature of the multiple criteria (Chen and Hwang, 1992), and the presence of subjectiveness and imprecision of the human decision making process (Yeh and Deng, 2004; Chen et al, 2006; Yang et al, 2007). The challenging of the decision making process comes from the need for making transparent and balanced decisions based on a comprehensive evaluation of all available alternatives in a timely manner while effectively considering the interest of various stakeholders in the decision making process (Deng and Wibowo, 2008). To effectively solving the multicriteria decision making problem, the application of fuzzy sets theory (Bellman and Zadeh, 1970) for adequately modelling the subjectiveness and imprecision has proven to be effective (Deng, 2005; Celik et al., 2009).

Much research has been done on the development of various fuzzy multicriteria analysis approaches for effectively addressing the general multicriteria decision making problem in a fuzzy environment (Ribeiro, 1996; Zimmermann, 2000; Deng and Yeh, 2006; Chou and Chang, 2008; Yu et al., 2009). These approaches are developed from various perspectives for helping the decision maker deal with the fuzzy multicriteria decision making problem with

respect to special circumstances in the real world setting. Commonly used approaches include mathematical programming approaches (Santhanam et al., 1989; Badri et al., 2001), scoring approaches (Henriksen and Traynor, 1999; Stewart and Mohamed, 2002), outranking approaches (Roy and Vincke, 1981; Brans, 1982; Brans and Vincke, 1985; Roy, 1990), and consensus based approaches (Tam and Tummala, 2001; Herrera-Viedma et al., 2005; Kengpol and Tuominen, 2006).

The purpose of this chapter is to conduct a comprehensive review of existing fuzzy multicriteria analysis approaches for justifying the need for this study. Such a review facilitates a better understanding of existing approaches and helps identify the drawbacks and concerns of existing approaches for solving the multicriteria analysis decision making problem. These drawbacks and concerns then serve as the fundamental motivation for conducting this research.

## **2.2 Multicriteria Decision Making With A Single Decision Maker**

Numerous approaches for solving the multicriteria decision making problem with a single decision maker have been reported in the literature (Saaty, 1980; Hwang and Yoon, 1981, Chen and Hwang, 1992; Yoon and Hwang 1995; Olson, 1996; Deng et al., 2000; El-Gayar and Leung, 2001; Blake and Carter, 2002; Deng and Wibowo, 2004; Kabassi and Virvou, 2004; Tzeng et al., 2005; Shyur and Shih, 2006; Wang and Elhag, 2006; Albadvi et al., 2007; Ng, 2008; Papadopoulos and Karagiannidis, 2008; Celik et al., 2009; Sun and Lin, 2009; Kaya and Kahraman, 2010). These approaches are developed from various perspectives for

addressing specific multicriteria decision making situations with respect to different circumstances.

Existing approaches for multicriteria decision making with a single decision maker can be classified into (a) utility based approaches (Hwang and Yoon, 1981; Chen and Hwang, 1992; Stewart and Mohamed, 2002; Brito and de Almeida, 2009), (b) mathematical programming approaches (Santhanam et al., 1989; Badri et al., 2001; Kameshwaran et al., 2007; Pati et al., 2008), (c) pairwise comparison based approaches (Saaty, 1980; Min, 1992; Al Khalil, 2002; Wei et al., 2005), and (d) outranking approaches (Vincke, 1992; Roy, 1996). To present a summarized view of existing approaches, a comparative analysis of these approaches is presented in the following with. Specific attention is paid in the discussion to the nature of these approaches, their applications, the merits of individual approaches, and the issues and concerns in applying these approaches in the real world setting.

### **2.2.1 Utility Based Approaches**

Utility based approaches are the most commonly used ones for effectively solving the multicriteria decision making problem. These approaches are developed along the line of the additive utility theory (Hwang and Yoon, 1981; Chen and Hwang, 1992; Olson, 1996). The overall objective of these approaches is to generate a cardinal performance index value for each alternative across all criteria and sub-criteria if existent in a given decision making situation on which a decision can be made (Deng, 2005). The representative approaches in this category for solving the multicriteria decision making problem in the literature are the simple additive weighting (SAW) approach (Hwang and Yoon, 1981; Buss, 1983; Olson, 1996; Chang and Yeh, 2001), the multiattribute utility theory (MAUT) approach (Mehrez,

1988; Stewart and Mohamed, 2002; Brito and de Almeida, 2009), the simple multiattribute rating technique (SMART) approach (Lootsma et al., 1990; Henriksen and Traynor, 1999), and the technique for order preference by similarity to ideal solution (TOPSIS) approach (Tsaour et al., 2002; Chen et al., 2006; Ertugrul and Gunes, 2007; Celik et al., 2009).

The SAW approach is also known as the weighted sum approach (Hwang and Yoon, 1981; Olson, 1996). This approach evaluates available alternatives using a numerical scale in relation to the performance of these alternatives and the importance of the criteria involved. The numerical scores are then aggregated for representing the overall preference of the decision maker in regard to individual alternatives (Chen and Hwang, 1992; Kabassi and Virvou, 2004). The SAW approach is the simplest and still the most widely used approach for solving the multicriteria decision making problem (Hwang and Yoon, 1981; Olson, 1996; Chang and Yeh, 2001; Virvou and Kabassi, 2004).

Buss (1983) adopts the SAW approach for evaluating and selecting information systems projects in an organization. With the application of this approach, the decision maker is required to provide numerical scores in relation to the performance of each information systems project with respect to each criterion and the importance of the criteria involved. The numerical scores are then aggregated for representing the overall performance of individual information systems projects across all the criteria. The information systems project with the highest performance index is selected for implementation. This approach is found to be simple to use (Chen and Hwang, 1992; Pohekar and Ramachandran, 2004). The approach, however, suffers from several limitations including the inadequacy in modelling the subjectiveness and imprecision of the human decision making process and the cognitive demanding on the decision maker in the decision making process.



Chang and Yeh (2001) apply the SAW approach for evaluating the airline competitiveness in Taiwan. Their approach takes into account the uncertainties of the decision making process and the conflicting nature of five competitiveness dimensions in the context of Taiwan's domestic airline market. The application of this approach helps an airline identify its competitive advantages relative to its competitors. This approach is found to be simple in both concept and computation. The approach, however, suffers from (a) the inadequacy in modelling the subjectiveness and imprecision of the human decision making process and (b) the demanding nature of the approach on the decision maker in the decision making process.

The MAUT approach is a systematic one for identifying and analyzing multiple criteria and sub-criteria of a multi-dimensional decision problem in order to provide a common basis for making decisions (Keeney and Raiffa, 1976; 1993). This approach helps the decision maker assign subjective assessments in numerous values with respect to the performance of each alternative across all criteria and sub-criteria and the relative importance of the evaluation and selection criteria and sub-criteria in regard to the overall objective of the problem. The overall utility value of each alternative across all evaluation and selection criteria and sub-criteria are obtained through aggregating the decision maker's subjective assessments along the line of the additive utility theory (Pohekar and Ramachandran, 2004). This approach is proved to be popular in real world applications due to the simplicity of the approach in concept and the easiness in use (Keeney and Raiffa, 1993).

Mehrez (1988) applies the MAUT approach for evaluating and selecting research and development projects in a small university laboratory. The application of this approach in this situation takes into account the uncertainties on both the technological and the marketing risks through assigning appropriate utility values to the corresponding alternative projects.

The project with the highest overall utility value is selected as the most appropriate project for development. This approach is found to be useful in dealing with a small size problem of project evaluation and selection. As the number of projects to be considered increases, the approach becomes impractical to use. As a consequence, the approach is not recommended for dealing with large-scale project evaluation and selection problems.

Stewart and Mohamed (2002) adopt the MAUT approach for selecting information systems projects in an organization. The approach considers the decision maker's preferences based on the business value and risk criteria in relation to four information systems projects. The performance of each alternative information systems project with respect to each evaluation and selection criterion and the weights of the criteria are determined numerically by the decision maker. The overall utility of each project can then be determined. This approach is found to be simple in concept and in use. This approach, however is criticized due to (a) its inability to deal with the subjectiveness and imprecision inherent in the decision making process and (b) the cognitive demanding nature on the decision maker in the evaluation and selection process.

Brito and de Almeida (2009) utilize the MAUT approach for assessing the natural gas pipelines in a natural gas distribution company. The approach takes into account the pipeline hazard scenarios and the risks by assigning appropriate utility values to the corresponding alternative pipelines. The pipeline with the highest overall utility value is selected to be the first to receive an allocation of resources from the supplementary prevention program. This approach, however is criticized due to its inability to deal with the subjectiveness and imprecision inherent in the decision making process.

The SMART approach is a simplified version of MAUT (Edwards, 1977). This approach evaluates available alternatives using standardized assessment scores, with zero representing the worst expected performance on a given criterion and one representing the best expected performance (Edwards, 1977; Edwards and Barron, 1994). The preference of each alternative is determined by calculating an overall decision score in each criterion and multiplying this by the weight value assigned to that criterion based on the utility theory (Chen and Hwang, 1992). The overall performance index for each alternative is determined using a linear additive value function. The alternative that produces the highest performance index over all criteria is the most desirable solution (Edwards and Barron, 1994; Pohekar and Ramachandran, 2004). The SMART approach is popular due to its simplicity in concept. The approach is also attractive due to the responses required of the decision maker and the manner in which these responses are analyzed (Edwards and Newman, 1982).

Lootsma et al. (1990) apply the SMART approach for selecting the most suitable information systems project. The approach allows the decision maker to allocate scores for alternative information systems projects with respect to each evaluation criterion. By aggregating these scores with the relative importance of the selection criteria, an overall ranking of information systems projects can be obtained on which the selection decision can be made (Avineri et al., 2000). This approach is reported to be popular due to its simplicity in concept and its easiness to use. The approach is, however, very demanding cognitively on the decision maker in the evaluation process and unable to effectively handle imprecise data in the evaluation process (Santhanam and Kyparisis, 1995; Lee and Kim, 2001).

Henriksen and Traynor (1999) use the SMART approach for solving an information systems project evaluation and selection problem in a federal research laboratory. The criteria

including the relevance, risk, reasonableness, and return on investment are considered. The tradeoffs among the evaluation criteria in the evaluation and selection process in order to calculate the overall project performance value are considered. This approach is found to be flexible to use because the decision maker can customize the approach to suit the specific objectives desired (Chen and Hwang, 1992; Olson, 1996). The approach, however is found to be ineffective in dealing with subjectiveness and imprecision inherent in the decision making process (Kahraman et al., 2003).

The TOPSIS approach is based on choosing on the best alternative having the shortest distance to the ideal solution and the farthest distance from the negative ideal solution (Hwang and Yoon, 1981). The advantage of the TOPSIS approach lies with the ability of the approach to help the decision maker organize the problems to be solved, and carry out analysis, comparisons and rankings of the alternatives based on the concept of distance between alternatives. Due to its simplicity in concept, the TOPSIS approach has been widely adopted to solve the multicriteria decision making problem in many different fields (Tsaour et al., 2002; Chen et al., 2006; Ertugrul and Gunes, 2007; Celik et al., 2009).

Tsaour et al. (2002) present the TOPSIS approach for assessing the service quality in an airline industry. The evaluation procedure in their study consists of several steps. First, the service quality criteria that customers consider important are identified. After constructing the evaluation criteria hierarchy, the criteria weights are determined by applying the analytical hierarchy process (AHP) approach. To determine the overall rankings of these airlines in regards to their service quality, a closeness coefficient is defined by calculating the distances to the fuzzy positive ideal solution and the fuzzy negative ideal solution. The study shows that approach is efficient for assessing the service quality problem in an airline industry.

Chen et al. (2006) use the TOPSIS approach for solving the supplier selection problem in a fuzzy environment. Linguistic variables are used to assess the weights of all selection criteria and the performance of each alternative with respect to each criterion. The decision matrix is converted into a fuzzy decision matrix, and a weighted-normalized fuzzy decision matrix is constructed once the decision maker's fuzzy ratings have been pooled. Based on the concept of the TOPSIS approach, a closeness coefficient is defined for determining the ranking order of all suppliers by calculating the distances to both the fuzzy positive-ideal solution and the fuzzy negative-ideal solution simultaneously. The approach is proved to be a useful decision making tool for solving the supplier selection problem. The approach is found to be very flexible which is capable of providing more objective information in the supplier selection and evaluation process.

Ertugrul and Gunes (2007) extend the TOPSIS approach for machine evaluation and selection in order to effectively model the subjectiveness and imprecision of the decision making process. Linguistic variables are used for representing the subjective assessments of the decision maker. Fuzzy numbers are used to approximate the linguistic variables due to their capacities of handling the ambiguity associated with the decision maker's judgements. To determine the overall order of the alternatives, a closeness coefficient is defined by calculating the distances to the fuzzy positive ideal solution and the fuzzy negative ideal solution. With the use of this extended TOPSIS approach, the uncertainty and vagueness from subjective perception and the experiences of decision maker is effectively represented, leading to effective decisions being made.

Wang and Chang (2007) apply the TOPSIS approach for evaluating and selecting training aircrafts under a fuzzy environment. The approach is used to deal with the training aircraft

selection problem involving several alternatives with multiple conflicting criteria. The subjective and imprecise assessments of the decision maker are handled with the use of linguistic terms approximated by triangular fuzzy numbers. The approach is employed to obtain a crisp overall performance value for each alternative on which a final decision is made. This approach is employed for four reasons: (a) the logic of the TOPSIS approach is rational and understandable; (b) the computation processes are straightforward; (c) the concept permits the selection of best alternatives for each criterion in a simple mathematical form, and (d) the importance weights are incorporated into the comparison procedures (Deng et al., 2000; Chu and Lin, 2002; Olson, 2004).

Dagdeviren et al. (2009) present the TOPSIS approach for weapon selection under a fuzzy environment. Linguistic variables are used to assess the weights of all selection criteria and the performance of each alternative with respect to each criterion. The decision matrix is converted into a fuzzy decision matrix, and a weighted-normalized fuzzy decision matrix is constructed once the decision maker's fuzzy ratings have been pooled. A closeness coefficient is defined for determining the ranking order of all suppliers by calculating the distances to both the fuzzy positive-ideal solution and the fuzzy negative-ideal solution simultaneously. The study shows that approach is efficient for solving the weapon selection problem under a fuzzy environment.

Sun and Lin (2009) demonstrate the applicability of the TOPSIS approach for evaluating the competitive advantages of shopping websites. In this study, criteria that influence the competitiveness of shopping websites are identified. The TOPSIS approach is used to determine the weights of the evaluation criteria and rank the alternatives of four shopping

websites. The study shows that the application of the TOPSIS approach enables a consistent and thorough study of all factors involved in this evaluation and selection process.

The TOPSIS approach is found to be intuitive and easy to understand and implement. It allows a straight linguistic definition of weights and ratings under each criterion without the need of cumbersome pairwise comparisons and the risk of inconsistencies (Deng et al., 2000). However, this approach is unable to provide mechanisms for weight elicitation and consistency checking for the subjective assessment process.

### **2.2.2 Mathematical Programming Approaches**

Mathematical programming approaches are commonly used for solving the general multicriteria decision making problem from the perspective of tangible costs and tangible benefits of individual alternatives in a given situation. Usually mathematical programming approaches require the decision maker to provide information on the desired levels of targets for various criteria in evaluating the attractiveness of individual alternatives. Prior to solving the general multicriteria decision making problem, the decision maker needs to provide an ordinal or cardinal ranking of the criteria with respect to the overall objective of the organization. An optimal solution that comes as close as possible to the prescribed set of targets in the order of priorities specified can then be determined (Saber and Ravindran, 1993; Olson, 1996).

The application of mathematical programming approaches generally requires the preference information of the decision maker in relation to the priorities of the evaluation criteria and objectives and the relationships between the objectives and criteria in consideration. Often

tangible cost and benefit data about individual alternatives should be available, and some kinds of linear relationships between the decision variables should be able to formalize in a given situation. The development in this area has been attributed to the decision problems where there is a large number of conflicting objectives that the decision maker has to incorporate in their decision making process (Kahraman, 2008).

Czajkowski and Jones (1986) apply an integer programming approach for evaluating and selecting interrelated research and development projects in a space technology planning situation. The approach considers the maximization of the utility and the cost reduction of new research and development projects. A single linear objective function is applied for aggregating these assessments with a weighting factor used to accommodate the fact that the objectives are of different priorities. By varying the weightings given to various objectives, the approach can produce a list of different solutions that are non-dominated. This approach is proved to be useful in some situations. The effectiveness of the approach, however, is often questioned due to the lack of a systematic approach to set priorities and trade-offs among objectives and criteria in a decision making process (Olson, 1996).

Santhanam et al. (1989) use a zero-one mathematical programming approach for evaluating and selecting information systems projects in a resource constrained environment. The approach is developed for addressing a decision making situation in which the information systems project evaluation and selection goals are conflicting in nature and measured in incommensurable units. Both objective and subjective data are considered simultaneously in this situation. The approach is proved to be effective for addressing the information systems project evaluation and selection problem involving constrained resource allocation (Deng and



Wibowo, 2004). This approach, however, is undesirable in some situations due to its inability for the decision maker to set up priorities among the objectives.

Schniederjans and Santhanam (1993) use a zero-one mathematical programming approach for evaluating and selecting projects. Their approach incorporates both the relative ranking of the project selection criteria and resource limitations of an organization in order to select the most suitable project for development. The approach is capable of generating a superior solution in a given evaluation and selection situation. It is attractive for addressing the project evaluation and selection problem because this approach can (a) avoid the possible solution bias, (b) consider all resource constraints, and (c) allow relative rankings of the evaluation and selection criteria in an easy manner. This approach, however, is often criticized due to the computation required when the number of criteria increases.

Santhanam and Kyparisis (1996) utilize a non-linear zero-one mathematical programming approach for solving the information systems project evaluation and selection problem. This approach can consider the technical interdependencies among the information systems projects in the information systems project evaluation and selection process. Although this approach is capable of considering the interdependencies inherent in the information systems project evaluation and selection process, the procedure involved in obtaining the solution is likely to get complicated as the number of information systems project alternatives increases.

Badri et al. (2001) adopt the goal programming approach for evaluating and selecting projects in the health care industry. Their approach considers the interdependence between the projects with a specific focus on the resource optimization in an organization. The approach is very much realistic as it can consider multiple objectives and multiple constraints with a

certain degree of flexibility. More importantly, this approach is capable of addressing various types of projects evaluation and selection situations. However, this approach like all other mathematical programming approaches requires tedious mathematical computation in the project evaluation and selection process.

Kameshwaran et al. (2007) use a revised goal programming approach for solving the e-procurement evaluation and selection problem. The approach is developed for helping the decision maker deal with the decision making problem where the e-procurement evaluation and selection goals measured in incommensurable units are conflicting. An example is used to illustrate the flexibility of this approach and its effectiveness in obtaining a satisfying solution with respect to the presence of various goals in a given situation. The limitation of this approach is that it requires the decision maker to specify the goals before the evaluation and selection process.

Pati et al. (2008) apply the goal programming approach for dealing with the paper recycling logistics problem. The approach can be used to address many of the problems and issues associated with the management of recycling logistics problem including (a) the need to increase reverse logistics cost for achieving quality recyclables by better segregation at sources and (b) benefiting environment through increased wastepaper recovery. This approach, however, requires tedious mathematical computation in the evaluation and selection process.

Chang and Lee (2010) present the goal programming approach for airport selection in low-cost carriers' networks. The approach is used to identify and select the best central airport and its connecting airports for providing the best overall optimal performance. By using the

proposed approach in the selection process, the decision maker is able to decide the number of destinations that should be operated and which airports to be included for producing the lowest operational cost, the highest revenue, and most passengers served, with the best overall performance. This approach is however, likely to get complicated as the number of airport alternatives increases.

Mathematical programming approaches in general are popular for solving the multicriteria decision making problem with respect to resource optimization. They are capable of incorporating multiple objectives while producing an optimal solution in a given situation in the decision making process (Chen and Hwang, 1992; Olson, 1996). The approach, however, is often criticized due to a number of limitations that the approach has in real world applications. For example, the decision maker has to specify goals and priorities before applying the approach which often is undesirable. In addition, the mathematical programming approach lacks a systematic procedure for setting priorities and trade-off among objectives and criteria (Lee and Kim, 2001; Gabriel et al., 2005). This limitation is even more evident while addressing the multicriteria decision making problem when (a) both tangible and intangible selection criteria need to be considered, (b) interdependent criteria and sub-criteria are involved, and (c) several decision makers are present in the multicriteria decision making process (Olson, 1996).

### **2.2.3 Pairwise Comparison Based Approaches**

The pairwise comparison based approaches allow the decision maker to first formulate the multicriteria decision making problem in a hierarchical structure consisting of the objectives, criteria, sub-criteria, and alternatives (Saaty, 1990). On the basis of the hierarchical structure

of the problem, the pairwise comparison technique is used for assessing the performance of alternatives with respect to each criterion and the relative importance of the evaluation and selection criteria. The best known approach in this category is the AHP approach (1980, 1990) with numerous applications ranging from the simple personal decision making problem to the complex capital intensive decision making situation (Vaidya and Kumar, 2006; Kang and Lee, 2007; Wong and Li, 2008).

The application of AHP consists of three stages including (a) hierarchic design, and (b) pairwise comparison, and (c) performance aggregation. The hierarchic design involves in formulating all the problem elements into a multi-level structure for a given multicriteria decision making problem. At each level, the elements are broken down into components, which constitute the level below. The pairwise comparison stage involves in comparing all elements at a level of the hierarchy in a pairwise manner with respect to each of the elements in the level directly above. A rating scale of 1 to 9 is used for representing the subjective assessments. The process of the pairwise comparison produces a relative ranking of priorities of the elements with respect to the criterion element they are compared against. The performance aggregation produces the final ranking of the elements at the bottom level (the alternatives) by aggregating the contribution of the elements at all levels to each of the alternatives (Al Khalil, 2002; Kuo et al., 2006).

Vellore and Olson (1991) present the application of the AHP approach for the computer aided design and drafting systems selection due to its capability in considering a number of objectives in the evaluation and selection of these systems. The AHP approach is used to consider (a) the cost factor, (b) the human factor, and (c) the impact of a new computer aided design and drafting system on the end-users in the organization concerned. The study shows

that the application of the AHP approach enables a consistent and thorough study of all factors involved in this evaluation and selection process. The approach provides a sound methodology to support complex decision making as it identifies the relative importance of all relevant factors in a simple manner.

Al Khalil (2002) uses the AHP approach to evaluate and select the most appropriate method for project delivery. This study shows that the AHP approach is capable of incorporating subjective assessments of the decision maker while assigning the relative importance of all the evaluation and selection criteria. Based on this information, the most appropriate project delivery method can be determined. The approach is simple to use and the computations can be run using available specialized software or using any spreadsheet program.

Wei et al. (2005) demonstrate the use of the AHP approach for evaluating and selecting enterprise resource systems. The AHP approach is applied for dealing with the subjectiveness and imprecision involved in the assessment of enterprise resource systems alternatives and for determining the relative importance weightings of all criteria. The approach is capable of assessing all criteria systematically. In addition, it can incorporate additional criteria or decision makers in the evaluation process.

Braglia et al. (2006) present the application of the AHP for evaluating and selecting computer maintenance system softwares. The approach is used to determine the performance of each project with respect to each criterion and the importance of the selection criteria pairwise. This approach enables the decision maker to restrict the evaluation and selection process to a limited number of software programmes that better suit the actual requirements of an

organization. As a result, decision makers can effectively select the most appropriate software for development.

Lin (2010) applies the AHP approach for evaluating course website quality. The AHP approach is applied to determine the relative weights of course website quality factors between high and low online learning experience groups. The results indicate that there are some similarities and differences between high and low experience groups with regard to the evaluation of course website quality. Analysis of the evaluation results help provide guidance to system designers in identifying the key factors facilitating course website development and finding the best policy for improving course website effectiveness.

The AHP approach has been widely used to address the general multicriteria evaluation and selection problems as above in the literature. This approach, however, is often criticized for its inconsistent ranking outcomes, inappropriateness of the crisp ratio representation, and tedious comparison processes when many criteria are involved (Yeh et al., 2000; Deng, 2005). With the use of the AHP approach, the decision maker is asked to give judgments about either the relative importance of the evaluation and selection criteria or its preference of one alternative on one criterion against another. This sounds simple and logic in real decision making situations. However, the pairwise comparison process becomes cumbersome, and the risk of generating inconsistent assessments increases when the number of alternatives and criteria increases, hence jeopardizing the practical applicability of the AHP approach (Chen and Hwang, 1992; Pohekar and Ramachandran, 2004).

Due to the limitation of the AHP approach in dealing with the subjectiveness and imprecision of the decision making process, numerous researches have been conducted on the

development of the fuzzy AHP approach for solving the multicriteria decision making problem in a fuzzy environment (Kwong and Bai, 2003; Kahraman et al., 2004; Celik et al., 2009). The fuzzy AHP approach is a systematic approach utilizes the concepts of fuzzy set theory and hierarchical structure analysis for making a decision (Kwong and Bai, 2003). This approach allows the decision maker to specify his/her preferences in the form of natural language or numerical value for determining the importance of each performance criterion (Cheng, 1996; Kahraman et al., 2004).

Kwong and Bai (2003) apply the fuzzy AHP approach in quality function deployment process. The fuzzy AHP approach together with the concept of fuzzy extent analysis is used to determine the criteria weights for the customer requirements in quality function deployment process. In this approach, triangular fuzzy numbers are used for the pairwise comparison. This approach is found to be simple and easy to implement for prioritizing customer requirements in the quality function deployment process.

Kahraman et al. (2004) use the fuzzy AHP approach for comparing catering service companies. With the application of this approach, the decision maker is able to specify his/her preferences in the form of natural language expressions in relation to the importance of each performance criterion including hygiene, quality of meals, and quality of service. Using fuzzy arithmetic and  $\alpha$ -cuts, the performance index of each catering company can be obtained on which the final decision can be made. The approach is found to be usefulness and efficient, particularly in a situation with vague and ill-defined data.

Duran and Aguilo (2008) present the fuzzy AHP approach for solving the computer-aided machine-tool selection problem. Triangular fuzzy numbers are used for representing the

decision maker's judgments. The concept of fuzzy synthetic extent analysis is applied for deciding the final priority of different decision criteria. This approach provides the flexibility and robustness needed for the decision maker in solving the computer-aided machine-tool selection problem.

Fu et al. (2008) demonstrate the use of the fuzzy AHP approach to study the impact of market freedom on the adoption of third-party electronic marketplaces. The decision choice of electronic marketplaces adoption that consisted of many strategic factors is constructed in terms of a three-layer hierarchical structure. The fuzzy AHP approach is used to estimate the relative importance of these individual strategic factors involved in the decision making process. This study provides insightful information to third-party electronic marketplace providers for improving their effectiveness and efficiency in resource allocation.

The fuzzy AHP approach, however, is not effective in dealing with various types of fuzzy numbers used for expressing the pairwise comparison outcomes. The pairwise comparison process also becomes cumbersome and the risk of inconsistencies increases when the number of alternatives and criteria increases which leads to unreliable decisions (Pohekar and Ramachandran, 2004).

#### **2.2.4 Outranking Approaches**

Outranking approaches are developed along the line of the outranking relation used to rank a set of alternatives (Chen and Hwang, 1992; Vincke, 1992; Olson, 1996). The main feature of these approaches is to compare all feasible alternatives by pair which leads to the development of some binary relations, crisp or fuzzy. Such binary relations are then exploited



in an appropriate manner in order to produce a final decision on the attractiveness of available alternatives (Vincke, 1992; Roy, 1996; Wang and Triantaphyllou, 2008). The representative outranking approaches include the elimination and choice translating reality (ELECTRE) approach and the preference ranking organization method for enrichment evaluation (PROMETHEE) approach.

The ELECTRE approach is developed on the analysis of the dominance relation among the alternatives in a given situation (Roy, 1990). The approach focuses on the study of outranking relations among alternatives through exploiting the notion of concordance and discordance among the alternatives (Vincke, 1992; Roy, 1996; Belton and Stewart, 2002). These outranking relations are determined based on the concordance and discordance indexes in order to analyze the outranking relations among the alternatives. The information required with the use of the ELECTRE approach includes the information among the criteria and the information within each criterion (Roy, 1996).

The ELECTRE approach comprises of two main procedures including (a) the construction of outranking relation(s) and (b) the exploitation of such outranking relations. The construction of outranking relation(s) aims at comparing alternatives pairwise in a comprehensive manner. The exploitation process is used to elaborate recommendations from the results obtained in the first phase. The nature of the recommendations depends on the problem. Each approach in this category in the literature is characterized by its construction and its exploitation process (Vanderpooten, 1990; Roy, 1991; Olson, 1996). To demonstrate how this approach is used for addressing the multicriteria decision making problem, an analysis of several developments in this area is presented in the following.

Zhang and Yuan (2005) apply the ELECTRE approach for addressing a power distribution system planning problem. Such a power distribution system planning problem involves multiple, conflicting criteria with the presence of the decision maker's subjective assessments which have to be considered simultaneously. The outranking relations are constructed for incorporating the decision maker's subjective assessments with respect to the multiple selection criteria in the decision making process. The result shows that the ELECTRE approach has the flexibility in utilizing the information provided by the decision maker. Such flexibility allows the decision maker to express, test and modify his/her subjective assessments in the interactive decision making process. The approach is proved to be practical and feasible for facilitating the decision making process in power distribution system planning.

Aguezzoul et al. (2006) present the ELECTRE approach for evaluating and selecting third-party logistics providers in supply chain management. The approach incorporates multiple selection criteria which are often in conflict with one another. It classifies third-party logistics providers from the best ones to the less important ones in relation to the selection criteria used. This approach is found to be effective in solving this decision problem. It is flexible to incorporate additional criteria as required by the decision maker in the decision making process.

Shanian and Savadogo (2006) use the ELECTRE approach for addressing a material selection problem in an organization. A decision matrix is introduced for the selection of the appropriate materials based on the design criteria. The weighted coefficients are obtained for every criterion using the entropy technique (Deng et al., 2000). The decision matrix and weighted coefficients are then taken as the input for the ELECTRE approach for the

development of the outranking relation. The study shows that ELECTRE is a suitable and efficient approach that can be used successfully in selecting a suitable material.

The ELECTRE approach is widely used in solving different multicriteria decision making problems in the literature (Roy and Vincke, 1981; Roy, 1990; Olson, 1996; Figueira and Roy, 2002; Roy and Slowinski, 2008). This approach, however, still has several shortcomings. For example, the ranking irregularities are a major issue that the ELECTRE approach suffers from. The ranking irregularities tend to occur when the alternatives appear to be very close to each other (Wang and Triantaphyllou, 2008). In addition, the outranking relation does not consider any interaction or dependence between criteria. It is purely based on the performance of each alternative against a given set of criteria. The concordance and discordance index does not take into account the relative importance of the associated sub-criteria (Figueira et al, 2005; Wang and Triantaphyllou, 2008).

The PROMETHEE approach is one of the most recent multicriteria analysis approaches. It is developed by Brans (1982) and further extended by Brans and Vincke (1985) and Brans and Mareschal (1994). This approach is based on a quite simple ranking concept with the introduction of the evaluation table. The implementation of the PROMETHEE approach requires two additional types of information including (a) information on the relative importance of the criteria, and (b) information on the decision maker's preference when comparing the contribution of the alternatives in terms of each criterion (Albadvi et al., 2007; Behzadian et al., 2010). This approach is well suitable to problems where a finite number of alternatives are to be ranked with respect to conflicting criteria.

Goumas and Lygerou (2000) present the application of the PROMETHEE approach for evaluating and ranking alternative energy exploitation projects. The approach is applied for the evaluation and ranking of alternative energy exploitation schemes of a low temperature geothermal field in Greece. The study shows that this approach is realistic capable of producing a reliable ranking for alternative energy exploitation scenarios, where the input data are subjective and imprecise. However, it is found that the approach is cognitively demanding on the decision maker in the evaluation process.

Albadvi et al. (2007) present a study of the PROMETHEE approach for evaluating and selecting superior stocks in stock trading. The required information for the evaluation and selection process are gathered and analyzed through the use of a structured questionnaire that is filled in by the experts. This approach is then applied to assess the superior stocks in Tehran Stock Exchange. The limitation of this approach is that it does not consider the conditions that govern the stock market such as political conditions and market situation.

Araz and Ozkarahan (2007) use the PROMETHEE approach for supplier evaluation and selection. The approach evaluates the performance of alternative suppliers by simultaneously considering supplier capabilities and other performance metrics indicated by the decision maker. As a result of this, the suppliers can be assessed and sorted based on their preference relations. The approach is flexible to use and can be used to identify the differences in performances across supplier groups. The approach is also useful in monitoring the suppliers' performances.

Diakoulaki et al. (2007) apply the PROMETHEE approach for assessing the prospects and opportunities induced from the exploitation of the flexible mechanisms of the Kyoto

Protocol. The developed approach focuses on the clean development mechanism by examining a number of countries where Greek enterprises are more likely to be activated. The analysis proceeds to a step-wise multicriteria screening procedure by which the most promising investment opportunities in the most advantageous host-countries are hierarchically ordered and further evaluated through a detailed financial assessment followed by sensitivity analysis. The obtained results show that the electricity generation sector offers quite promising investment opportunities for Greek interests. The approach is found to be simple to use and provides a consistent outcome to the decision maker.

Queiruga et al. (2008) demonstrate the use of the PROMETHEE approach for evaluating and selecting the locations of recycling plant in Spain. The required information for the evaluation and selection process is gathered through the use of surveys from the decision maker. The approach is then applied to rank Spanish municipalities according to their appropriateness for the installation of waste recycling plants. This approach is found to be useful for solving the recycling plant problem.

The PROMETHEE approach, however, does not provide structuring possibilities in the problem solving process. In the case of multiple evaluation and selection criteria, this approach may become very difficult for the decision maker to obtain a clear view of the problem and to evaluate the results (Goumas and Lygerou, 2000; Behzadian et al., 2010). The PROMETHEE approach also requires specific guidelines for determining the weights and the generalized criteria which may be difficult to achieve by an inexperienced decision maker (Pohekar and Ramachandran, 2004).

## **2.3 Multicriteria Group Decision Making**

Multicriteria group decision making involves in evaluating and selecting alternatives with respect to multiple, often conflicting criteria with the participation of multiple decision makers (Herrera et al., 1996). In such situations, how to obtain the maximum degree of agreement or consensus from these decision makers for the given alternatives is of importance. Much research has been done on the development of multicriteria group decision making approaches for dealing with the multicriteria group decision making problem (Kacprzyk et al., 1992; Tavana et al., 1996; Herrera et al., 1997; Easley et al., 2000; Kahraman et al., 2003; Wang and Lin, 2003; Dias and Climaco, 2005; Fenton and Wang, 2006; Pasi and Yager, 2006; Kuo et al., 2007; Wu and Chen, 2007; Lin et al., 2008; Xu, 2009; Yeh and Chang, 2009; Yu et al., 2009; Alonso et al., 2010; Boroushaki and Malczewski, 2010; Dong et al., 2010; Sanayei et al., 2010). These approaches can be classified into to be (a) majority based approaches, (b) ranking based approaches, and (c) consensus based approaches.

### **2.3.1 Majority Based Approaches**

Majority based approaches focus on a voting process among the decision makers in order to obtain the decision. The final decision is made based on the opinion of majority decision makers (Laukkanen et al., 2002; Hiltunen et al., 2008). These approaches have been widely adopted to solve the group decision making problem in many different fields (Liu and Hai, 2005; Pasi and Yager, 2006; Boroushaki and Malczewski, 2010).

Laukkanen et al. (2002) apply the majority based approach for solving the natural resource management problem. In this approach, the concept based on cumulative voting is used to deal with the group decision making problem. In this situation, the decision makers have a certain amount of points to allocate between alternatives which enable the decision makers to express not only their preferences but also the intensities of their preferences. The weakness of this approach is the voting procedures are easy to be manipulated (Nurmi, 1987).

Liu and Hai (2005) present the majority based approach for evaluating and selecting suppliers. This approach allows the decision makers to assign their votes in assessing the performance of suppliers and determining the importance of the criteria for solving the supplier selection problem. The supplier with the highest vote is selected as the most appropriate supplier for selection. This approach is popular due its simplicity in concept (Herrera-Viedma et al., 2005). It is, however, often criticized due to the time consuming voting process and the inadequacy in modelling the subjectiveness and imprecision of the human decision making process.

Pasi and Yager (2006) present the majority based approach for solving the multicriteria group decision making problem in a fuzzy environment. Using a linguistic quantifier, the fuzzy majority concept is used to generate a group solution that corresponds to the majority of the decision makers' preferences. The linguistic quantifier guides the aggregation process of the individual judgments in such a way that there is no need for determining the rankings of the alternatives from individual decision makers. However, the approach becomes time consuming when the number of decision makers increases.

Hiltunen et al. (2008) present the application of the majority based approach for dealing with strategic forest planning selection problem. The approach takes into account the decision makers' preference rankings of the alternatives using the Borda technique. In this approach, each decision maker is requested to give  $n$  votes to the most preferred alternative,  $n-1$  for the second preferred alternative, and finally one vote for the least preferred alternative (Saari, 1999). The alternative with the highest number of votes is selected. This sounds simple and logical in real decision making situations. However, the group decision making process becomes when the number of alternatives and criteria increases. This approach is also found to encourage insincere voting behavior (Brams and Fishburn, 2005).

Boroushaki and Malczewski (2010) demonstrate the use of the majority based approach for dealing with the multicriteria group decision making problem under uncertainty. The procedure for solving the group decision making problem involves two stages. The first stage is operationalized by a linguistic quantifier-guided ordered weighted averaging (OWA) (Yager, 1996) procedure to create individual decision maker's solution maps. Individual maps are combined using the fuzzy majority procedure to generate the group solution map which synthesizes the majority of the decision makers' preferences. This approach is capable of dealing with the subjectiveness and imprecision inherent in the decision making process. This approach however is criticized due to the cognitive demanding nature on the decision makers in the group decision making process.

The majority based approach is found to be popular among the decision makers due to its simplicity in concept. The approach is also attractive due to the manner in which the responses from the decision makers are obtained (Hiltunen et al., 2008). However, this approach has several weaknesses including (a) cognitively demanding on the decision



makers, (b) ineffective in dealing with the subjectiveness and imprecision inherent in the decision making process, and (c) time consuming voting process (Wibowo and Deng, 2009).

### **2.3.2 Ranking Based Approaches**

Ranking based approaches require individual decision makers to allocate numerical scores in assessing the performance of alternatives and the importance of the criteria. The obtained scores are then aggregated on which the alternative with the highest aggregated score is selected (Chen and Hwang, 1992; Ribeiro, 1996; Kahraman, 2008). These approaches are commonly used for solving the multicriteria decision making problem involving multiple decision makers (Li and Yang, 2004; Mikhailov, 2004; Fan et al., 2006; Jiang et al., 2008).

Li and Yang (2004) present a linear programming approach for solving the multicriteria group decision making problem in a fuzzy environment. In this approach, linguistic variables are used to capture fuzziness of the decision making process. A new vertex method is proposed to calculate the distance between triangular fuzzy numbers. Group consistency and inconsistency indices are defined on the basis of preferences between alternatives given by decision makers. Each alternative is assessed on the basis of its distance to a fuzzy positive ideal solution which is unknown. The fuzzy positive ideal solution and the weights of criteria are then estimated using a new linear programming approach based upon the group consistency and inconsistency indices defined. Finally, the distance of each alternative to fuzzy positive ideal solution can be calculated to determine the ranking order of all alternatives. The lower value of the distance for an alternative indicates that the alternative is closer to fuzzy positive ideal solution. The approach can be used to generate consistent and reliable ranking order of alternatives. This approach, however, is undesirable when the

number of criteria increases in a real decision making situation due to the increased mathematical computation required.

Mikhailov (2004) uses a group fuzzy preference programming approach for deriving group priorities from crisp pairwise comparison judgements provided by the decision makers. The approach is developed to maximize the group's overall satisfaction with the group solution. The approach combines the group synthesis and prioritization stages into a coherent integrated framework, which does not need additional aggregation procedures. The approach can easily deal with missing judgements and provides a meaningful indicator for measuring the level of group satisfaction and group consistency. However, the approach is cognitive demanding on the decision makers in the subjective group decision making process.

Ölçer and Odabasi (2005) presents a fuzzy multicriteria decision making approach for dealing with the multicriteria group decision making problem under uncertainty. In the proposed approach, a criterion-based aggregation technique for multiple decision makers is employed and used for dealing with fuzzy opinion aggregation for the subjective criteria of the decision making problem. The approach is found to be simple to use and easy to understand. However the approach can be time consuming due to the multiple activities involved in the group decision making process.

Fan et al. (2006) use the goal programming approach for solving the group decision making problem where the preference information on alternatives provided by decision makers is represented in two different formats: (a) multiplicative preference relations and (b) fuzzy preference relations. In order to narrow the gap between the collective opinion and each decision maker's opinion, a linear goal programming approach is applied to integrate the two

different formats of preference relations and to compute the collective ranking values of the alternatives. The ranking of alternatives or selection of the most desirable alternative(s) is then obtained directly from the computed collective ranking values. The advantage of this approach is that it keeps the collective opinion as close to each decision maker's opinion as possible, and thus improves the group consensus. The weakness of this approach lies with the tedious mathematical computation involved in the use of goal programming in the problem solving process.

Li (2007) develops a compromise ratio approach for dealing with the multicriteria group decision making problem in a fuzzy environment. The criteria weights and the performance ratings of each alternative with respect to each criterion are represented by linguistic terms approximated by trapezoid fuzzy numbers. A fuzzy distance measure is developed approximated by trapezoid fuzzy numbers. The approach is developed by introducing the ranking index based on the concept that the chosen alternative should be as close as possible to the positive ideal solution and as far away from the negative ideal solution as possible. This approach is found to be simple in concept and use. However, this approach is not suitable to solve the large scale multicriteria group decision making problem as it is more computationally challenging.

Jiang et al. (2008) apply a goal programming approach for solving the group decision making problem with multi-granularity linguistic information. In this approach, the multi-granularity linguistic terms provided by decision makers are expressed in the form of fuzzy number. A linear goal programming approach is set up to aggregate the fuzzy numbers and to compute the collective ranking values of alternatives. Then, a fuzzy preference relation on the pairwise comparisons of the collective ranking values of alternatives is constructed using the

dominance possibility degree of the comparison between the fuzzy numbers. By applying a non-dominance choice degree to this fuzzy preference relation, the ranking of alternatives is determined and the most desirable alternative is selected. The approach offers a systematic way to address the group decision making problem. This approach, however, is criticized due to the mathematical computation involved with the use of the goal programming approach.

Yeh and Chang (2009) present the fuzzy multicriteria group decision making approach for evaluating decision alternatives involving subjective judgments made by a group of decision makers. A pairwise comparison process is used to help individual decision makers make comparative judgments, and a linguistic rating method is used for making absolute judgments. A hierarchical weighting method is developed to assess the weights of a large number of evaluation criteria by pairwise comparisons. To reflect the inherent imprecision of subjective judgments, individual assessments are aggregated as a group assessment using triangular fuzzy numbers. To obtain a cardinal preference value for each decision alternative, a new fuzzy multicriteria decision making algorithm is developed by extending the concept of the degree of optimality to incorporate criteria weights in the distance measurement. This approach is capable of dealing with the subjectiveness and imprecision inherent in the decision making process. However, the decision making process can be time consuming due to the multiple activities involved in the evaluation and selection process.

Fan and Liu (2010) use the fuzzy multicriteria group decision making approach for solving the group decision making problem with multi-granularity uncertain linguistic information. To process multi-granularity uncertain linguistic information, a formula for transforming multi-granularity uncertain linguistic terms into trapezoidal fuzzy numbers is given. Thus, the group decision making problem with multi-granularity uncertain linguistic information is

changed into the one with fuzzy numbers. To solve the group decision making problem, an appropriate extension of the TOPSIS approach is conducted. Fuzzy positive ideal solution and fuzzy negative ideal solution are defined, respectively. The closeness coefficient is obtained to determine the ranking order of all alternatives by calculating the distances to both fuzzy positive and negative ideal solutions, simultaneously. With the use of this TOPSIS approach, the uncertainty and vagueness from subjective perception and the experiences of decision makers is effectively represented, leading to effective decisions being made. However, the approach is found to be ineffective as the number of criteria and alternatives increases.

Ranking based approaches discussed above are proved to be popular for solving the multicriteria decision making problem involving multiple decision makers. However, most of these approaches are very demanding cognitively on the decision makers in the evaluation and selection process. These approaches may also involve tedious mathematical computation which is undesirable (Kahraman, 2008).

### **2.3.3 Consensus Based Approaches**

Consensus based approaches recognize the importance of reaching a certain level of agreement among the decision makers in selecting alternatives for facilitating the acceptance of the decision made. It usually involves in an interactive process for building consensus (Herrera-Viedma et al., 2005; Xu, 2009; Parreiras et al., 2010). Consensus based approaches have been widely used to solve the multicriteria group decision making problem in many different fields (Tam and Tummala, 2001; Leyva-López and Fernández-González, 2003; Herrera-Viedma et al., 2005; Kengpol and Tuominen, 2006; Xu and Chen, 2007).

Tam and Tummala (2001) present the application of the AHP approach for dealing with the vendor selection problem in a telecommunication company. The AHP approach is applied for dealing with the ambiguities involved in the assessment of vendor alternatives and for determining the relative importance weightings of all criteria from multiple decision makers in order to arrive at a consensus decision. The approach is capable of assessing all criteria systematically. In addition, it is capable of reducing the amount of time required in the evaluation process. However, the pairwise comparison process becomes cumbersome, and the risk of generating inconsistent assessments increases when the number of alternatives and criteria increases.

Muralidharan et al. (2002) apply the consensus building approach for combining decision makers' preferences into one consensus ranking in solving the problem of evaluating and selecting supplier in multicriteria group decision making. The approach is proved to be practical in group decision making. However, this approach requires tedious mathematical computation in the evaluation and selection process.

Leyva-López and Fernández-González (2003) present an extension of the ELECTRE approach to assist decision makers in achieving a consensus decision. The approach is used to obtain a fuzzy binary relation for representing the decision makers' collective preference. The approach is found to be flexible in utilizing the information provided by the decision makers. However, this approach is found to be ineffective in dealing with subjectiveness and imprecision of the decision making process.

Wang and Lin (2003) use the fuzzy multicriteria group decision making approach for dealing with the configuration items problem. Fuzzy sets theory (Zadeh, 1973) is used to represent

the evaluation results of candidate items since most information available is subjective and imprecise and is usually expressed in a nature language by individual decision makers. The fuzzy multicriteria group decision approach based on the concept of fuzzy preference relation and fuzzy majority is used to rank configuration items into a partial order or a complete order according to their importance. The approach, however, obviously suffers from several limitations including the inadequacy in modelling the subjectiveness and imprecision of the human decision making process and the cognitive demanding on the decision makers in the decision making process.

Herrera-Viedma et al. (2005) demonstrate the application of the consensus based approach for solving the multicriteria group decision making problem. This approach is based on (a) a multi-granular linguistic methodology and (b) two consensus criteria, consensus degrees and proximity measures. The multi-granular linguistic methodology is introduced to allow the unification of the different linguistic domains to facilitate the calculus of consensus degrees and proximity measures on the basis of decision makers' opinions. The consensus degrees assess the agreement amongst all the decision makers' opinions, while the proximity measures are used to find out how far the individual opinions are from the group opinion. The approach is able to cope with group decision making problems with multi-granular linguistic preference relations. However, the group decision making process becomes cumbersome when the number of alternatives and criteria increases.

Lo et al. (2005) present a novel approach for measuring consensus in the risk assessment process. In this approach, a new similarity measure of vague sets is introduced. A fuzzy synthetic evaluation method is employed to attain the consensus interval of the group via the agreement matrix for solving the group decision making problem. The approach is found to

be usefulness and efficient, particularly in a situation with vague and ill-defined data. The weakness of this approach lies with the tedious mathematical computation involved in the problem solving process.

Kengpol and Tuominen (2006) apply an integrated approach to enable decision makers achieve an overall consensus in the evaluation of information technology proposals. The analytical network process (ANP) is applied to set priorities and trade-off among objectives and criteria. The Delphi approach is used to evoke expert group opinions and to determine a degree of interdependence relationship between the evaluation and selection criteria. The information obtained from the ANP and Delphi is then used in the maximize agreement heuristic (MAH) approach for determining the final outcome. The advantage of this approach lies in its capability in performing an in-depth quantitative and qualitative analysis for achieving the overall consensus ranking. The Delphi process, however, can be very time consuming in the problem solving process.

Herrera-Viedma et al. (2007) present the consensus based approach that is capable of performing both consensus and consistency measures. In addition, the consensus reaching process is guided automatically, without moderator, through both consensus and consistency criteria. To do that, a feedback mechanism is developed to generate advice on how decision makers should change or complete their preferences in order to reach a solution with high consensus and consistency degrees. In each consensus round, decision makers are given information on how to change their preferences, and to estimate missing values if their corresponding preference relation is incomplete. Additionally, a consensus and consistency based induced ordered weighted averaging operator to aggregate the decision makers' preferences is introduced. The advantage of this approach is that it supports the management



of incomplete information and it allows the decision makers to achieve consistent solutions with a high level of agreement. The limitation of this approach is that it can be time consuming due to the multiple activities involved in the evaluation and selection process.

Xu and Chen (2007) use an interactive approach for dealing with a multicriteria group decision making problem in a fuzzy environment. The approach transforms fuzzy decision matrices into their expected decision matrices, constructs the corresponding normalized expected decision matrices, and then aggregates these normalized expected decision matrices. Through interactivity, the decision makers can provide and modify their preference information gradually in the process of decision making so as to make the decision result more reasonable. This approach is simple in concept and easy to use. It is, however, very demanding cognitively on the decision maker in the evaluation process. It cannot effectively handle imprecise data in the evaluation process.

Kahraman et al. (2009) develop the consensus based multicriteria group decision making approach for selecting and ranking information systems providers. A measure for the consensus level of the group preferences is developed to satisfy an acceptable level of group agreement. The Spearman coefficients are used for calculating both the aggregated rank order and each decision maker's rank order. The group and the individual evaluations are gathered through a fuzzy TOPSIS approach. The approach is found to be very flexible which is capable of providing more objective information in the group decision making process. However, this approach is unable to provide mechanisms for weight elicitation and consistency checking for the subjective assessment process.

Xu (2009) presents a novel approach for reaching consensus among group opinions. In the process of the group decision making, each decision maker is required to provide his/her preferences over the alternatives with respect to each criterion which leads to the construction of an individual decision matrix. The developed approach first aggregates these individual decision matrices into a group decision matrix by using the additive weighted aggregation (AWA) operator, and then establishes a convergent iterative algorithm to gain a consentaneous group decision matrix. Based on the consentaneous group decision matrix, the approach utilizes the AWA operator to derive the overall preference values of alternatives, by which the most desirable alternative can be obtained. This approach is found to be simple and straightforward in solving the group decision making problem. However, this approach is not suitable to solve the large scale group decision making problem as it is more computationally challenging.

Parreiras et al. (2010) use a flexible consensus approach for solving the multicriteria group decision making problem under linguistic assessments. Their approach allows the generation of a consistent collective opinion based on information provided by individual decision makers in terms of multi-granular fuzzy estimates. The approach is found to be intuitive and flexible as it allows the decision makers to change their own opinions and the moderator to change the weights associated with each opinion during the decision making process. The limitation of the proposed approach lies in the computationally challenging nature of the problem solving process.

The discussion above shows that there are numerous consensus based approaches for solving the multicriteria group decision making problem. These approaches are found to be useful in dealing with the multicriteria group decision making problem as they are capable of allowing

a certain level of consensus among the decision makers to be achieved. However, most of these approaches can be very cognitively demanding on the decision makers in the multicriteria group decision making process. In addition, some of these approaches require tedious mathematical computation in solving the multicriteria group decision making process.

## **2.4 Concluding Remarks**

This chapter has reviewed related literature on multicriteria analysis decision making for solving real decision making problems. This literature review is organized from the perspectives of (a) multicriteria decision making with a single decision maker and (b) multicriteria group decision making. To justify the need for the developments of novel approaches for effectively addressing the multicriteria decision making problem, the chapter has highlighted the major drawbacks of existing approaches for solving the multicriteria decision making problem.

The review shows that most existing multicriteria analysis approaches suffer from various drawbacks in handling the complexity of the multicriteria decision making process. These shortcomings include (a) requirements of complicated mathematical programming, (b) inability to handle the subjectiveness and imprecision present in the decision making process, (c) unreliability and complexity of the ranking procedures in comparing the utility values, and (d) cognitively demanding on the decision maker(s). To address these shortcomings, this study aims to develop effective approaches for dealing with multicriteria decision making problems with respect to specific circumstances that the problem is in.

## Chapter 3

### Problem Formulation and Developments

#### 3.1 Introduction

Multicriteria decision making refers to selecting or ranking alternative(s) from available alternatives with respect to multiple, usually conflicting criteria involving a single decision maker or multiple decision makers (Chen and Hwang, 1992; Deng and Wibowo, 2008; Yeh et al., 2009). Dealing with multicriteria decision making problems is complex and challenging due to the nature of the problem, the size of the problem, the amount of information available, the number of decision maker(s) involved, and the time available for making the decision (Yeh and Deng, 2004; Chen et al., 2006; Yang et al., 2007). Quite often both qualitative and quantitative data are present simultaneously in a given situation (Deng and Wibowo, 2008). Making effective decisions requires adequate consideration of these requirements in a fuzzy environment.

Tremendous efforts have been spent and significant advances have been made towards the development of various fuzzy multicriteria analysis approaches for solving various multicriteria decision making problems. However, there is no best approach for solving the general multicriteria decision making problem. This is because most existing approaches suffer from various shortcomings including (a) the failure to adequately handle the subjectiveness and imprecision inherent in the evaluation process (Deng and Wibowo, 2008), (b) the requirement of a complicated mathematical computation (Lee and Kim, 2001; Gabriel

et al., 2005), and (c) the failure to adequately handle the various requirements of the decision maker(s) (Yeh et al., 2010). In particular, existing approaches often ignore the requirements of individual decision maker(s) and often require rigorous assumptions. This is impractical, as decision problems vary greatly in real situations. To adequately address these requirements, several special decision contexts and specific requirements are identified along with their associated challenges in fuzzy multicriteria decision making. The need for the development of novel approaches in effectively solving the fuzzy multicriteria decision making problem is discussed.

The purpose of this chapter is to formulate the general fuzzy multicriteria decision making problem for facilitating the methodology development. To justify the need for the development of novel approaches for facilitating the multicriteria decision making process, specific decision contexts for the multicriteria decision making problem are discussed. To facilitate the understanding on the developments to be presented in later chapters, an overview of the developments is presented.

In what follows, the general fuzzy multicriteria decision making problem is first presented for facilitating the methodology development. Several special decision contexts for the multicriteria decision making problem along with their associated challenges and specific requirements are then discussed. Finally, an overview of the developments is outlined for paving the way for the presentation of Chapters 4-12.

### 3.2 The Fuzzy Multicriteria Decision Making Problem

The general fuzzy multicriteria decision making problem usually involves in the selection or ranking of one or more alternatives from a set of  $n$  available alternatives  $A_i (i = 1, 2, \dots, n)$ . These alternatives are to be assessed based on  $m$  evaluation and selection criteria  $C_j (j = 1, 2, \dots, m)$ . Qualitative as well as quantitative assessments are usually required from the decision maker  $D_k (k = 1, 2, \dots, s)$  for evaluating the performance of each alternative with respect to each criterion, denoted as  $x_{ij} (i = 1, 2, \dots, n, j = 1, 2, \dots, m)$ . The general fuzzy multicriteria decision making problem can therefore be represented as

$$\Phi = \{ X^k, W^k \} \quad (3.1)$$

where a decision matrix for all the alternatives and a weighting vector for the criteria can be obtained respectively as follows:

$$X^k = \begin{bmatrix} x_{11}^k & x_{12}^k & \dots & x_{1m}^k \\ x_{21}^k & x_{22}^k & \dots & x_{2m}^k \\ \dots & \dots & \dots & \dots \\ x_{n1}^k & x_{n2}^k & \dots & x_{nm}^k \end{bmatrix}; k = 1, 2, \dots, s. \quad (3.2)$$

$$w^k = (w_1^k, w_2^k, \dots, w_m^k); \quad k = 1, 2, \dots, s. \quad (3.3)$$

Subjectiveness and imprecision is existent in multicriteria decision making due to (a) incomplete information, (b) abundant information, (c) conflicting evidence, (d) ambiguous information, and (e) subjective information (Samson et al., 2009; Yeh et al., 2010). To adequately model the subjectiveness and imprecision in multicriteria decision making, linguistic terms approximated by triangular fuzzy numbers are often used to express the decision maker's subjective assessments. The use of triangular fuzzy numbers is attributed to their simplicity in both concept and computation (Kahraman, 2008; Ma et al., 2010).

Depending on the problem involved, various linguistic terms can be used based on the specific requirement of the decision maker. This would allow the decision maker to specify the importance of criteria, and to effectively assess the performance of each alternative in satisfying these criteria. It would greatly reduce the decision maker's cognitive burden and facilitate the making of consistent assessments in a fuzzy environment (Ding and Liang, 2005; Zhang and Lu, 2009; Kaya and Kahraman, 2010).

For computational simplicity, triangular fuzzy numbers are usually used to represent the approximate distribution of these linguistic terms with values ranged between 1 and 9, denoted as  $(a_1, a_2, a_3)$  where  $1 < a_1 < a_2 < a_3 < 9$ . In the fuzzy multicriteria decision making process,  $a_2$  is used to represent the most possible value of the term, and  $a_1$  and  $a_3$  are representing the lower and upper bounds respectively used to reflect the fuzziness of the term (Zimmermann, 1987; Chen and Hwang, 1992; Deng and Yeh, 1997).

As an example, the states and their linguistic terms of two linguistic variables: Capability and Importance (Chen and Hwang, 1992; Yeh and Deng, 1997) can be represented as in Table 3.1. These two linguistic variables are often used to express the decision maker's subjective judgments in the fuzzy multicriteria decision making process for solving the fuzzy multicriteria decision making problem (Yeh et al., 1998).

Given the decision problem structure described as above, the overall objective of the fuzzy multicriteria decision problem is to rank all alternatives available by giving each of them an overall performance index with respect to all criteria. This overall performance index is usually determined by effectively and efficiently aggregating the criteria weights and

alternative performance ratings described as above with respect to the requirements of a specific fuzzy multicriteria decision making problem.

**Table 3.1 Linguistic Terms for Representing Two Linguistic Variables: Capability and Importance**

Capability		Importance	
Assessment	Membership Function	Assessment	Membership Function
Very Poor (VP)	(1, 1, 3)	Very Low (VL)	(1, 1, 3)
Poor (P)	(1, 3, 5)	Low (L)	(1, 3, 5)
Fair (F)	(3, 5, 7)	Medium (M)	(3, 5, 7)
Good (G)	(5, 7, 9)	High (H)	(5, 7, 9)
Very Good (VG)	(7, 9, 9)	Very High (VH)	(7, 9, 9)

### 3.3 Decision Contexts and Challenges

In real-world applications, the requirements of each specific fuzzy multicriteria decision making problem are quite different as previously discussed. To adequately handle these requirements, several special decision contexts are identified along with their associated challenges and specific requirements in the fuzzy multicriteria decision making problem. The motivation of this research comes from the need to develop simple, comprehensible and efficient approaches, which are capable of addressing individual requirements under a specific decision context (Zimmermann, 2000; Deng, 2005; Celik et al., 2009).

In this study, the term “decision context” is used to describe the circumstances that surround a particular situation including the decision settings and the requirements of decision



maker(s). The term “decision setting” is defined in terms of (a) the number of decision makers involved, (b) the size of problem which include the number of criteria and alternatives, and (c) the type of data including qualitative or quantitative data.

To justify the motivation for the development of novel approaches for facilitating the decision making process in evaluating and selecting the most appropriate alternative from available alternatives in a given decision making situation, four decision contexts are identified in the following, along with their challenges and requirements.

### **3.3.1 Decision Context A**

#### *3.3.1.1 Decision Context A*

- (a) The decision problem involves in one single decision maker.
- (b) The decision problem requires effective consideration of the multi-dimensional nature of the decision making process.
- (c) Multiple selection criteria are present in the decision making process.
- (d) Subjectiveness and imprecision are present in the multicriteria decision making process due to the subjective nature of the human decision making process.

#### *3.3.1.2 Challenges for Decision Context A*

- (a) A new approach needs to be developed for effectively reducing the cognitive demanding on the decision maker and adequately modelling the subjectiveness and imprecision of the decision making process.

### **3.3.2 Decision Context B**

#### *3.3.2.1 Decision Context B*

- (a) The decision problem involves in more than one decision maker.
- (b) The decision makers are faced with the inherent subjectiveness and imprecision of the multicriteria decision making process.
- (c) The evaluation criteria are generally multi-dimensional in nature and a simultaneous consideration of those multiple criteria is required.

#### *3.3.2.2 Challenges for Decision Context B*

- (a) A structured approach capable of adequately fulfilling the interest of various decision makers in the multicriteria decision making process is required for effectively solving the multicriteria group decision making problem.

### **3.3.3 Decision Context C**

#### *3.3.3.1 Decision Context C*

- (a) The decision problem involves in a group of decision makers.
- (b) The decision problem requires effectively considering multiple selection criteria simultaneously.
- (c) Subjective and imprecise assessments are involved.
- (d) A certain level of consensus needs to be achieved among the group of decision makers based on the individual ranking outcomes.

#### *3.3.3.2 Challenges for Decision Context C*

- (a) New consensus algorithm needs to be developed for considering the interest of different decision makers in the decision making process.

- (b) A decision support system (DSS) needs to be developed incorporating the proposed consensus building algorithm for facilitating the consensus building process in solving the multicriteria group decision making problem.

### **3.3.4 Decision Context D**

#### *3.3.4.1 Decision Context D*

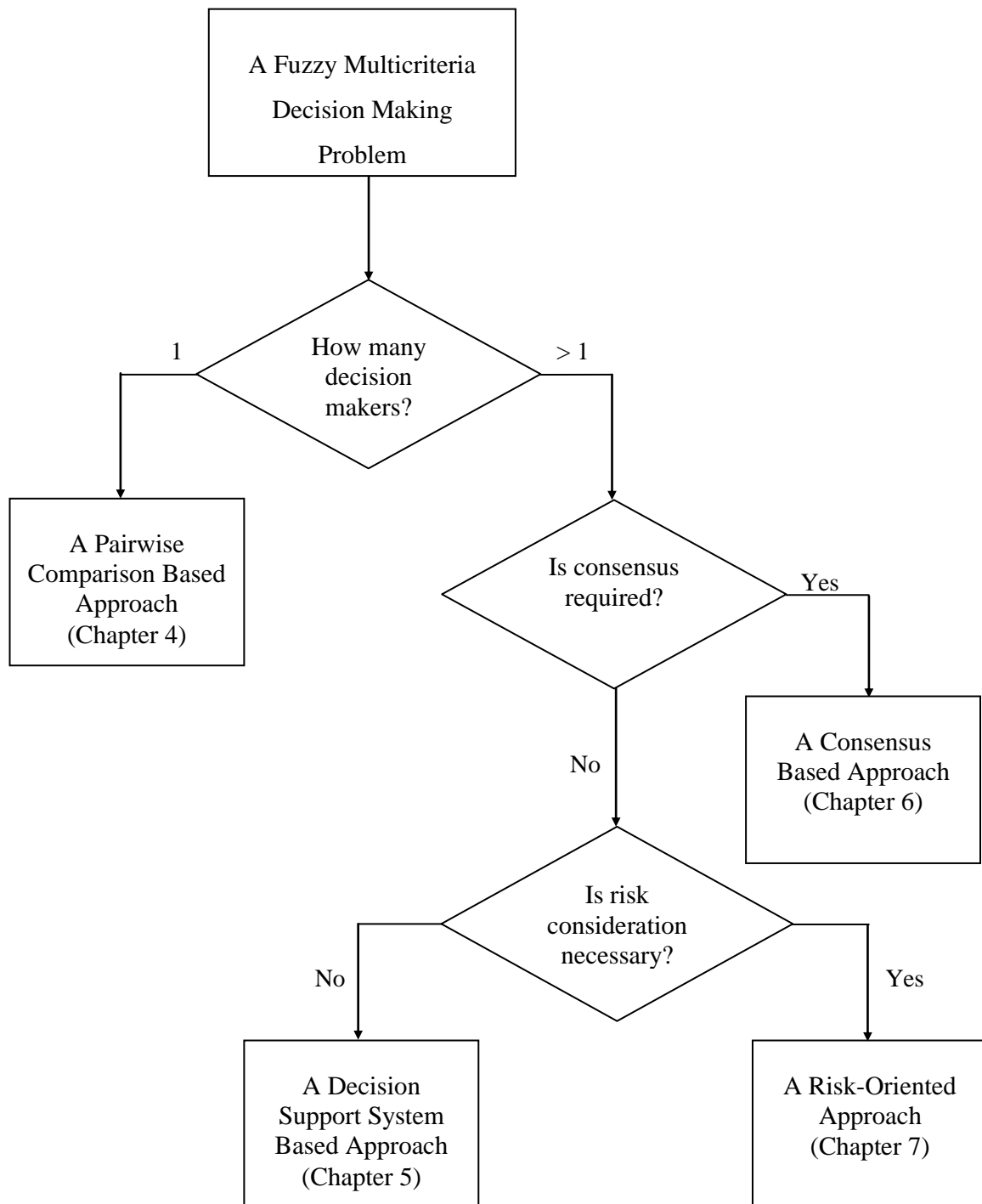
- (a) The decision problem involves in a group of decision makers.
- (b) Risk is present due to the subjectiveness and imprecision inherent.
- (c) The decision problem requires effectively modelling the subjectiveness and imprecision in multicriteria group decision making in order to adequately handle the inherent risk.

#### *3.3.4.2 Challenges for Decision Context D*

- (a) There is a need in developing a new approach for adequately modelling the inherent risk in the multicriteria group decision making process.

## **3.4 An Overview of the Developments**

To effectively address the context specific challenges and requirements described as above in fuzzy multicriteria decision making, the development of novel approaches is desirable for assisting the decision maker(s) to make effective decisions in a simple and consistent manner. To this end, four novel approaches have been developed in this study for effectively dealing with the challenges and requirements for various decision contexts. Figure 3.1 shows an overview of these developments.



**Figure 3.1 An Overview of the Developments**

Chapter 4 develops a pairwise comparison based approach for addressing the challenges and requirements for Decision Context A. As a result, effective decisions can be made due to the great reduction of the cognitive demanding on the decision maker and the adequate modelling of the subjectiveness and imprecision in the decision making process.

Chapter 5 develops a DSS based approach for addressing the challenges and requirements in relation to Decision Context B. To avoid the complex and unreliable process of comparing fuzzy numbers usually required in fuzzy multicriteria analysis (Shih et al., 2005), a new algorithm is developed based on the degree of dominance (Deng, 1999) and the degree of optimality (Yeh et al., 2000). A DSS is introduced to facilitate the multicriteria group decision making process efficiently and effectively.

Chapter 6 presents a consensus based approach for addressing the challenges and requirements associated with Decision Context C. To facilitate its use in solving real world decision making problems, a DSS is proposed incorporating the proposed consensus building algorithm for facilitating the consensus building process in solving the multicriteria group decision making problem.

A risk-oriented approach is developed in Chapter 7 to meet the challenges and requirements for Decision Context D. The approach is capable of adequately modelling the inherent risk in multicriteria group decision making. The concept of ideal solutions is applied for calculating the overall performance index for each alternative across all criteria so that the complex and unreliable process of comparing fuzzy utilities is avoided.

The empirical studies of four real fuzzy multicriteria decision making problems have been presented in this research for demonstrating the applicability of the four novel approaches developed in solving practical fuzzy multicriteria decision making problems. Each of these four real fuzzy multicriteria decision making problems has different requirements, thus requiring different approaches for effectively dealing with them. These studies show that the four novel approaches developed are effective and efficient for solving the fuzzy multicriteria decision making problem in a simple and straightforward manner.

### **3.5 Concluding Remarks**

The chapter has presented the general fuzzy multicriteria decision making problem for facilitating the methodology development. To justify the need for the development of novel approaches for facilitating the multicriteria decision making process, specific decision contexts for the multicriteria decision making problem are discussed. To facilitate the understanding on the developments to be presented in later chapters, an overview of the developments is presented.

## Chapter 4

# Pairwise Comparison Based Multicriteria Decision

## Making under Uncertainty

### 4.1 Introduction

Multicriteria decision making refers to selecting or ranking alternative(s) from available alternatives with respect to multiple, usually conflicting criteria. In practical situations, subjectiveness and imprecision are always present in the multicriteria decision making process (Chen and Hwang, 1992; Deng, 2005). They usually originate from assessing the criteria importance and alternative performance in the face of (a) incomplete information, (b) non-obtainable information, and (c) partial ignorance in the multicriteria evaluation process (Deng and Yeh, 2006). To ensure an effective decision is made, it is important to adequately handle the subjectiveness and imprecision inherent in the multicriteria decision making process.

The purpose of this chapter is to address the Decision Context A as outlined in Chapter 3 by developing a pairwise comparison based approach for effectively solving the multicriteria decision making problem. To effectively model the inherent subjectiveness and imprecision, linguistic variables approximated by fuzzy numbers are used. To effectively reduce the decision maker's cognitive burden in the evaluation process, the pairwise comparison technique is adopted. To avoid the complicated and unreliable process of comparing and

ranking fuzzy utilities, the concept of the degree of dominance between alternatives is introduced for calculating an overall performance index for every alternative across all criteria. As a result, effective evaluation and selection decisions can be made due to the great reduction of the cognitive demanding on the decision maker and the adequate modelling of the subjectiveness and imprecision in the decision making process.

In what follows, some preliminary concepts in fuzzy sets theory and fuzzy extent analysis are first discussed for paving the way for the methodology development. A pairwise comparison based approach is then presented for effectively solving a real multicriteria decision making problem.

## 4.2 Some Preliminary Concepts

### 4.2.1 Fuzzy Sets

A fuzzy set  $A$  of the universe of discourse  $U$  is defined by a membership function  $\mu_A: U \rightarrow [0,1]$ , where  $\mu_A(x)$  is the degree of membership of  $x$  in  $A$ , and  $[0,1]$  is the closed unit interval on the real line  $R$ . Very often, fuzzy set  $A$  of  $U$  can be expressed as

$$A = \left\{ \frac{\mu_A(x)}{x}, x \in U, \mu_A(x) \in [0, 1] \right\} \quad (4.1)$$

As a comparison, a classical non-fuzzy set  $B$  is usually defined as a binary membership function  $\mu_B: U \rightarrow \{0,1\}$ , where  $\{0,1\}$  is the set of values 0 and 1 rather than an interval, and  $\mu_B(x) = 1$  or 0 indicates whether element  $x$  in  $U$  is a member of the set  $B$  or not.



### 4.2.2 Fuzzy Numbers

A fuzzy number is a convex fuzzy set (Zadeh, 1965), characterized by a given interval of real numbers, each with a grade of membership between 0 and 1. Its membership function is piecewise continuous, and satisfies the conditions of (a)  $\mu_A(x) = 0$  for each  $x \in (-\infty, a_1] \cup [a_4, +\infty)$ , (b)  $\mu_A(x)$  is non-decreasing on  $[a_1, a_2]$  and non-increasing on  $[a_3, a_4]$ ,  $\mu_A(x) = 1$  for each  $x \in [a_2, a_3]$  where  $a_1 \leq a_2 \leq a_3 \leq a_4$  are real numbers in the real line  $R$ .

Triangular fuzzy numbers are a special class of fuzzy number, defined by three real numbers, often expressed as  $(a_1, a_2, a_3)$ . Their membership functions are usually described as

$$\mu_A(x) = \begin{cases} \frac{x - a_1}{a_2 - a_1}, & a_1 \leq x \leq a_2, \\ \frac{a_3 - x}{a_3 - a_2}, & a_2 \leq x \leq a_3, \\ 0, & \text{otherwise.} \end{cases} \quad (4.2)$$

where  $a_2$  is the most possible value of fuzzy number  $A$ , and  $a_1$  and  $a_3$  are the lower and upper bounds respectively which is often used to illustrate the fuzziness of the data evaluated.

### 4.2.3 Arithmetic Operations on Fuzzy Numbers

Arithmetic operations on fuzzy numbers are a direct application of the extension principle in fuzzy mathematics (Kaufmann, 1975; Kaufmann and Gupta, 1991; Zimmermann, 2000). Only the arithmetic operations related to triangular fuzzy numbers are illustrated in this study. Further references can be found in Kaufmann (1975), Dubois and Prade (1980), Kaufmann and Gupta (1985, 1991), and Zimmermann (1987, 1996).

Let  $A = (a_1, a_2, a_3)$  and  $B = (b_1, b_2, b_3)$  be two positive triangular fuzzy numbers. The basic fuzzy arithmetic operations on these fuzzy numbers are defined as

- (a) Inverse:  $A^{-1} = (\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}),$
- (b) Addition:  $A + B = (a_1 + b_1, a_2 + b_2, a_3 + b_3),$
- (c) Subtraction:  $A - B = (a_1 - b_3, a_2 - b_2, a_3 - b_1),$
- (d) Scalar Multiplication:  $\forall k > 0, k \in R, kA = (ka_1, ka_2, ka_3),$   
 $\forall k < 0, k \in R, kA = (ka_3, ka_2, ka_1),$
- (e) Multiplication:  $AB = (a_1b_1, a_2b_2, a_3b_3),$
- (e) Division:  $\frac{A}{B} = (\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}).$

Fuzzy numbers are widely used to approximate the linguistic variables used for expressing the decision maker's subjective assessments in the human decision making process. To facilitate the making of pairwise comparison, linguistic variables originally defined by Saaty (1990) in the development of the AHP approach are used. These linguistic variables are approximated by triangular fuzzy numbers as defined in Table 4.1.

**Table 4.1 Linguistic Variables and Their Fuzzy Number Approximations for Making Pairwise Comparison Assessments**

Linguistic Variables	Fuzzy Number	Membership Function
Very Poor (VP)	$\bar{1}$	(1, 1, 3)
Poor (P)	$\bar{3}$	(1, 3, 5)
Fair (F)	$\bar{5}$	(3, 5, 7)
Good (G)	$\bar{7}$	(5, 7, 9)
Very Good (VG)	$\bar{9}$	(7, 9, 9)

#### 4.2.4 Fuzzy Synthetic Extent Analysis

The concept of fuzzy extent analysis is used for deriving criteria weights and alternative performance ratings from the reciprocal matrices resulting from the pairwise comparison process (Chang, 1996; Deng, 1999). Due to its simplicity in concept and computational efficiency, the concept of fuzzy synthetic analysis has been employed in a number of applications including selection of computer integrated manufacturing systems (Bozdağ et al., 2003), facility location selection (Kahraman et al., 2003), evaluation of success factors in e-commerce (Kong and Liu, 2005), project selection (Mahmoodzadeh et al., 2007), e-market selection (Deng and Molla, 2008), weapon selection (Dagdeviren et al., 2009), and personnel selection (Güngör et al., 2009).

Assume that  $X = \{x_1, x_2, \dots, x_n\}$  is an object set, and  $U = \{u_1, u_2, \dots, u_m\}$  is a goal set. Fuzzy assessments are performed with respect to each object for each goal respectively, resulting in  $m$  extent analysis values for each object, given as  $\mu_i^1, \mu_i^2, \dots, \mu_i^m, i=1, 2, \dots, n$ , where all  $\mu_i^j (i=1, 2, \dots, n; j=1, 2, \dots, m)$  are fuzzy numbers representing the performance of the object  $x_i$  with regard to each goal  $u_j$ . Using fuzzy synthetic extent analysis (Chang, 1992), the value of fuzzy synthetic extent with respect to the  $i^{th}$  object  $x_i$  that represents the overall performance of the object across all goals involved can be determined by

$$S_i = \frac{\sum_{j=1}^m \mu_i^j}{\sum_{i=1}^n \sum_{j=1}^m \mu_i^j}, \quad i=1, 2, \dots, n. \quad (4.3)$$

### 4.3 A Pairwise Comparison Based Approach

Evaluating and selecting multicriteria decisions is complex and challenging, due to (a) the multi-dimensional nature of the selection process, (b) the presence of multiple selection criteria, (c) the existence of subjectiveness and imprecision in the decision making process, and (d) the cognitive demand on the decision maker in making subjective assessments (Hwang and Yoon, 1981; Deng, 1999, Yeh et al., 2010). To effectively overcome these concerns, this section presents a pairwise comparison based approach for solving the multicriteria selection problem as described in Decision Context A.

The decision process starts with the determination of the performance of alternatives with respect to each criterion and the relative importance of the selection criteria. To greatly reduce the cognitive demanding on the decision maker, the pairwise comparison technique used in the AHP (Saaty, 1990) is applied. Using the linguistic variables as described in Table 4.1, a pairwise judgment matrix can be obtained for alternative performance or criteria importance respectively as in (4.4) where  $k = n$  or  $m$  and  $a_{12} = a_{21}$ .

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1k} \\ a_{21} & 1 & \dots & a_{2k} \\ \dots & \dots & \dots & \dots \\ a_{k1} & a_{k2} & \dots & 1 \end{bmatrix} \quad (4.4)$$

Using the fuzzy synthetic extent analysis as described in (4.3), the criteria weightings ( $w_j$ ) and performance rating ( $x_{ij}$ ) with respect to criterion  $C_j$  can be obtained, resulting in the determination of the fuzzy decision matrix for the alternatives and the fuzzy weighting vector for the selection criteria as

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (4.5)$$

$$W = (w_1, w_2, \dots, w_m) \quad (4.6)$$

With the use of interval arithmetic (Kaufmann and Gupta, 1991), the weighted fuzzy performance matrix for representing the overall performance of all alternatives in regard to each criterion can then be determined by multiplying the criteria weights ( $w_j$ ) and the alternative performance ratings ( $x_{ij}$ ), given as follows:

$$Z = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \dots & w_m x_{1m} \\ w_1 x_{21} & w_2 x_{22} & \dots & w_m x_{2m} \\ \dots & \dots & \dots & \dots \\ w_1 x_{n1} & w_1 x_{n2} & \dots & w_m x_{nm} \end{bmatrix} \quad (4.7)$$

To avoid the complicated and unreliable process of comparing and ranking fuzzy utilities for determining the overall performance of each alternative across all criteria (Yeh et al., 1999; Shih et al., 2005; Zhang et al., 2010), the concept of the degree of dominance between alternatives is introduced (Yeh and Deng, 2004; Georgescu, 2005). The degree of dominance concept is originally used to compare fuzzy numbers  $A$  and  $B$  as to how much larger  $A$  is than  $B$ . The fuzzy set difference  $D_{A-B}$  between  $A$  and  $B$  can be calculated by fuzzy subtraction (Kaufmann and Gupta, 1991; Chen and Hwang, 1992) as

$$D_{A-B} = A - B = \{(z, \mu_{A-B}(z)), z \in R\} \quad (4.8)$$

where the membership function of  $D_{A-B}$  is defined as

$$\mu_{D_{A-B}}(z) = \sup_{z=x-y} (\min(\mu_A(x), \mu_B(y)), x, y \in X).$$

To determine how much larger  $A$  is than  $B$ , a defuzzification process is required to extract a single scalar value from  $D_{A-B}$ , which can best represent  $D_{A-B}$  (Liu et al., 2011). Using the centroid method commonly regarded as an effective defuzzification technique, the degree of dominance of  $A$  over  $B$  is determined by

$$d(A-B) = \frac{\int_{S(D_{A-B})} z \mu_{D_{A-B}}(z) dz}{\int_{S(D_{A-B})} \mu_{D_{A-B}}(z) dz} \quad (4.9)$$

where  $S(D_{A-B}) = \{z, \mu_{A-B}(z) > 0, z \in R\}$  is the support of  $D_{A-B}$ .  $A$  dominates  $B$  if  $d(A-B) > 0$ , and  $A$  is dominated by  $B$  if  $d(A-B) < 0$ .

To apply the concept of the degree of dominance, a common comparison base needs to be set up with respect to the weighted performance matrix in (4.7). In this regard, the fuzzy maximum ( $M_{\max}^j$ ) and the fuzzy minimum ( $M_{\min}^j$ ) (Chen, 1985) are introduced. Given the fuzzy vector  $(w_j x_{1j}, w_j x_{2j}, \dots, w_j x_{nj})$  of the weighted performance matrix for criterion  $C_j$ ,  $M_{\max}^j$  and  $M_{\min}^j$  (Chen, 1985) can be determined as in (4.8)-(4.11) which represent respectively the best and the worst fuzzy performance ratings among all the alternatives with respect to criterion  $C_j$ .

$$\mu_{M_{\max}^j}(x) = \begin{cases} \frac{x - x_{\min}^j}{x_{\max}^j - x_{\min}^j}, & x_{\min}^j \leq x \leq x_{\max}^j, \\ 0, & \text{otherwise} \end{cases} \quad (4.10)$$

$$\mu_{M_{\min}^j}(x) = \begin{cases} \frac{x_{\max}^j - x}{x_{\max}^j - x_{\min}^j}, & x_{\min}^j \leq x \leq x_{\max}^j, \\ 0, & \text{otherwise} \end{cases} \quad (4.11)$$

where  $i = 1, 2, \dots, n$ ;  $j = 1, 2, \dots, m$ ;  $x_{\max}^j = \sup \bigcup_{i=1}^n \{x \in R \text{ and } 0 < \mu_{w_j x_{ij}}(x) < 1\}$ , and

$$x_{\min}^j = \inf \bigcup_{i=1}^n \{x \in R \text{ and } 0 < \mu_{w_j x_{ij}}(x) < 1\}.$$

With the determination of  $M_{\max}^j$  and  $M_{\min}^j$  as above, the degree to which the fuzzy maximum dominates the weighted fuzzy performance ( $w_j x_{ij}$ ) of alternative  $A_i$  with respect to criterion  $C_j$  can be expressed as

$$d_{ij}^+ = d(M_{\max}^j - w_j x_{ij}) = \int D_{(M_{\max}^j - w_j x_{ij})}(\alpha) d\alpha \quad (4.12)$$

where

$$D_{M_{\max}^j - w_j x_{ij}}(\alpha) = \begin{cases} \frac{d_{(M_{\max}^j - w_j x_{ij})}^{L\alpha} + d_{(M_{\max}^j - w_j x_{ij})}^{R\alpha}}{2}, & 0 \leq \alpha \leq 1, \\ 0, & \text{otherwise.} \end{cases} \quad (4.13)$$

Similarly, the degree of dominance of the weighted fuzzy performance ( $w_j x_{ij}$ ) of alternative  $A_i$  over the fuzzy minimum with respect to criterion  $C_j$  is given as

$$d_{ij}^- = d(w_j x_{ij} - M_{\min}^j) = \int D_{(w_j x_{ij} - M_{\min}^j)}(\alpha) d\alpha \quad (4.14)$$

where

$$D_{(w_j x_{ij} - M_{\min}^j)}(\alpha) = \begin{cases} \frac{d_{(w_j x_{ij} - M_{\min}^j)}^{L\alpha} + d_{(w_j x_{ij} - M_{\min}^j)}^{R\alpha}}{2}, & 0 \leq \alpha \leq 1, \\ 0, & \text{otherwise.} \end{cases} \quad (4.15)$$

Zeleny (1982) first introduces the concept of the ideal solution in decision analysis as the best or desired decision outcome for a given decision situation. Hwang and Yoon (1981) further extend this concept to include the negative ideal solution in order to avoid the worst decision outcome. This concept has since been widely used in developing various methodologies for solving practical decision problems (Yeh et al., 1999; Yeh et al., 2000). This is due to (a) its simplicity and comprehensibility in concept, and (b) its ability to measure the relative performance of the decision alternatives in a simple mathematical form.

In line with the above concept, the positive fuzzy ideal solution consisting of the fuzzy maximum with respect to each criterion across all alternatives and the negative fuzzy ideal solution consisting of the fuzzy minimum in regard to each criterion across all alternatives can be determined as follows:

$$A_{\max} = (M_{\max}^1, M_{\max}^2, \dots, M_{\max}^m) \quad (4.16)$$

$$A_{\min} = (M_{\min}^1, M_{\min}^2, \dots, M_{\min}^m) \quad (4.17)$$

The degree of dominance that the positive ideal solution is on alternative  $A_i$  and the degree of dominance that each alternative  $A_i$  has on the negative ideal solution can be calculated respectively as:

$$d_i^+ = \sum_{j=1}^m d_{ij}^+ \quad (4.18)$$

$$d_i^- = \sum_{j=1}^m d_{ij}^- \quad (4.19)$$

An alternative is preferred if it is dominated by the positive fuzzy ideal solution by a smaller degree, and at the same time dominates the negative fuzzy ideal solution by a larger degree (Yeh et al., 2000). Following this principle, an overall performance index for each alternative  $A_i$  across all criteria can be calculated by

$$P_i = \frac{(d_i^-)^2}{(d_i^+)^2 + (d_i^-)^2} \quad (4.20)$$

The larger the performance index  $P_i$ , the more preferred the alternative  $A_i$ .



The discussion above can be summarized in an algorithm as follows:

- Step 1. Obtain the criteria weightings ( $w_j$ ) and performance rating ( $x_{ij}$ ) with respect to criterion  $C_j$  using fuzzy synthetic extent analysis as described in (4.3).
- Step 2. Determine the fuzzy decision matrix for the alternatives, as expressed in (4.5).
- Step 3. Determine the fuzzy weighting vector for the selection criteria as shown in (4.6).
- Step 4. Calculate the weighted fuzzy performance matrix by multiplying (4.5) and (4.6) as given in (4.7).
- Step 5. Determine the fuzzy maximum which represents the best fuzzy performance ratings among all the alternatives as the positive fuzzy ideal solution by (4.10)
- Step 6. Determine the fuzzy minimum which represents the worst fuzzy performance ratings among all the alternatives as the negative fuzzy ideal solution by (4.11).
- Step 7. Calculate the degree of dominance that the positive fuzzy ideal solution has on each alternative by (4.12), (4.13), (4.16), and (4.18).
- Step 8. Calculate the degree of dominance that the positive fuzzy ideal solution has on each alternative by (4.14), (4.15), (4.17), and (4.19).
- Step 9. Compute the overall performance index for each alternative by (4.20).
- Step 10. Rank the alternatives in descending order of their overall performance index values.

## 4.4 Concluding Remarks

The complexity of the multicriteria decision making process is due to the multi-dimensional nature of the decision making process, the conflicting nature of the multiple selection criteria, the presence of subjectiveness and imprecision of the human decision making process, and the cognitive demand on the decision maker in making subjective assessments. The challenging of the selection process comes from the need for making transparent and balanced decisions in a timely manner.

This chapter has presented the development of a pairwise comparison based approach for effectively solving the multicriteria decision making problem in a simple and straightforward manner. To effectively model the inherent subjectiveness and imprecision, linguistic variables approximated by fuzzy numbers are used. To greatly reduce the cognitive demanding on the decision maker, the pairwise comparison technique is adopted. To avoid the complicated and unreliable process of comparing and ranking fuzzy utilities, the concept of the degree of dominance between alternatives is introduced for calculating an overall performance index for every alternative across all criteria.

The pairwise comparison based approach developed in this chapter has several advantages including (a) its ability to adequately handle the subjectiveness and imprecision of the weighting process, (b) its ability to effectively deal with the multi-dimensional nature of the selection process, (c) its simplicity and comprehensibility of the underlying concept, and (d) its capability to effectively reduce the cognitive demanding on the decision maker. As a result, effective decisions can be made based on the proper consideration of all these issues.

## Chapter 5

# Effective Decision Support for Fuzzy Multicriteria

## Group Decision Making

### 5.1 Introduction

The increasing complexity of the business environment nowadays makes it less possible for a single decision maker to consider all the relevant aspects of a decision making problem (Herrera-Viedma et al., 2005; Yue, 2011). In practical situations, many decision making processes take place in a group setting. Moving from a single decision maker's setting to the group decision makers' setting increases the complexity in the decision making process. An effective consideration of the requirements of multiple decision makers is of a critical concern for achieving a decision outcome that best satisfies all the decision makers involved.

Multicriteria group decision making involves in evaluating and selecting alternatives with respect to multiple, often conflicting criteria with the participation of multiple decision makers (Herrera et al., 1996; Muralidharan et al., 2002). Much research has been done on the development of numerous approaches for dealing with the multicriteria group decision making problem (Muralidharan et al., 2002; Liu and Hai, 2005; Sreekumar and Mahapatra, 2009). These approaches are developed from various perspectives for addressing specific multicriteria group decision making situations. Even though these approaches are useful for solving the multicriteria group decision making problem, many of these approaches are found

to have various shortcomings including (a) the failure to adequately handle the various requirements of the decision maker(s), (b) tedious mathematical computation required, and (c) cognitively very demanding on the decision maker(s) (Wang and Lin, 2003; Kahraman, 2008; Yeh et al., 2010).

To address these issues with the existing approaches, it is desirable to develop a structured approach capable of dealing with the multicriteria group decision making problem. The development of decision support system (DSS) is therefore desirable for helping the decision makers solve the multicriteria group decision making problem in an efficient and effective manner (Deng and Wibowo, 2009). The application of such a DSS would greatly reduce the complexity of the multicriteria group decision making process.

A DSS is a computer-based information system used to support decision making activities in situation where it is not possible or not desirable to have an automated system for performing the entire decision making process (Turban et al., 2008). A DSS uses computers to (a) assist managers in their decision processes in semi-structured problems, (b) support, rather than replace, managerial judgments, and (c) improve the effectiveness of decision making rather than its efficiency. The development of DSS is therefore desirable for helping decision makers solve the multicriteria group decision making problem in an efficient and effective manner.

The purpose of this chapter is to address the Decision Context B outlined in Chapter 3 through the development of the DSS based approach for solving the multicriteria group decision making problem in which both the criteria importance and alternative performance are presented subjectively by multiple decision makers. A fuzzy multicriteria group decision

making algorithm is developed for dealing with the multicriteria group decision making problem. A multicriteria DSS is introduced to facilitate the multicriteria group decision making process effectively and efficiently. To model the subjectiveness and imprecision of the human decision making process, linguistic terms characterized by triangular fuzzy numbers are used. To avoid the unreliable process of comparing fuzzy numbers for determining the overall performance of each alternative across all criteria, the concept of the degree of dominance between alternatives is used. To calculate the overall performance index for each alternative across all criteria, the concept of ideal solutions is applied. This leads to effective decisions being made in the multicriteria group decision making problem.

In what follows, a fuzzy multicriteria group decision making algorithm for dealing with the fuzzy multicriteria group decision making problem is first presented. A multicriteria DSS is then presented to facilitate the multicriteria group decision making process in an effective and efficient manner.

## **5.2 A Fuzzy Multicriteria Group Decision Making Algorithm**

Dealing with multicriteria group decisions is always complex and challenging, due to (a) the subjectiveness and imprecision of the human decision making process, (b) the cognitive demand on the decision makers in making subjective assessments, and (c) the comparison of fuzzy numbers which is complex and unreliable (Hwang and Yoon, 1981; Deng, 1999, Yeh et al., 2010). To address these issues, a new algorithm is developed in this chapter for solving the multicriteria group decision making problem.

The proposed algorithm starts with assessing the performance rating of each decision alternative  $A_i$  ( $i = 1, 2, \dots, n$ ) with respect to each criterion  $C_j$  ( $j = 1, 2, \dots, m$ ) by each decision maker  $D_k$  ( $k = 1, 2, \dots, s$ ) using the linguistic terms defined as in Table 3.1. As a result,  $s$  decision matrices can be obtained as

$$Y^k = \begin{bmatrix} y_{11}^k & y_{12}^k & \dots & y_{1m}^k \\ y_{21}^k & y_{22}^k & \dots & y_{2m}^k \\ \dots & \dots & \dots & \dots \\ y_{n1}^k & y_{n2}^k & \dots & y_{nm}^k \end{bmatrix}; \quad k = 1, 2, \dots, s. \quad (5.1)$$

where  $y_{ij}^k$  is the fuzzy assessment of decision maker  $D_k$  about the performance rating of alternative  $A_i$  with respect to criterion  $C_j$ .

The relative importance of the evaluation criteria  $C_j$  can be assessed qualitatively by each decision maker  $D_k$  ( $k = 1, 2, \dots, s$ ) using the linguistic terms defined in Table 3.1. As a result,  $s$  fuzzy weight vectors can be obtained as

$$w^k = (w_1^k, w_2^k, \dots, w_m^k); \quad k = 1, 2, \dots, s. \quad (5.2)$$

By averaging the fuzzy assessments made by individual decision makers as given in (5.1) and (5.2), the overall fuzzy decision matrix and the fuzzy weight vector can be obtained as

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (5.3)$$

$$W = (w_1, w_2, \dots, w_m) \quad (5.4)$$

where  $x_{ij} = \frac{\sum_{k=1}^s y_{ij}^k}{s}$  and  $w_j = \frac{\sum_{k=1}^s w_j^k}{s}$ .

The weighted fuzzy performance matrix that represents the overall performance of each alternative on each criterion can be determined by multiplying the fuzzy criteria weights ( $w_j$ ) by the alternatives' fuzzy performance ratings ( $x_{ij}$ ) as

$$Z = \begin{bmatrix} w_1x_{11} & w_2x_{12} & \cdot & w_mx_{1m} \\ w_1x_{21} & w_2x_{22} & \cdot & w_mx_{2m} \\ \cdot & \cdot & \cdot & \cdot \\ w_1x_{n1} & w_1x_{n2} & \cdot & w_mx_{nm} \end{bmatrix} \quad (5.5)$$

To avoid the unreliable process of comparing fuzzy numbers for determining the overall performance of each alternative across all criteria, the algorithm uses the concept of the degree of dominance between alternatives. The degree of dominance concept is originally used by Yeh and Deng (2004) to compare fuzzy numbers  $A$  and  $B$  as to how much larger  $A$  is than  $B$ . The fuzzy number ranking method based on this concept compares favorably with comparable methods examined. The fuzzy set difference  $D_{A-B}$  between  $A$  and  $B$  is calculated by fuzzy subtraction as

$$D_{A-B} = A - B = \{(z, \mu_{A-B}(z)), z \in R\} \quad (5.6)$$

where the membership function of  $D_{A-B}$  is defined as

$$\mu_{D_{A-B}}(z) = \sup_{z=x-y} (\min(\mu_A(x), \mu_B(y)), x, y \in X). \quad (5.7)$$

To determine how much larger  $A$  is than  $B$ , a defuzzification process is required to extract a single scalar value from  $D_{A-B}$ , which can best represent  $D_{A-B}$ . Using the mean value of fuzzy numbers method (i.e. the average of value intervals of all  $\alpha$ -cuts), the degree of dominance of  $A$  over  $B$  is determined by

$$d(A - B) = \int_0^1 D_{A-B}(\alpha) d\alpha \quad (5.8)$$

$$D_{A-B}(\alpha) = \begin{cases} (d_{A-B}^{L\alpha} + d_{A-B}^{R\alpha})/2, & 0 \leq \alpha \leq 1, \\ 0, & \text{otherwise.} \end{cases} \quad (5.9)$$

where  $d_{A-B}^{L\alpha}$  and  $d_{A-B}^{R\alpha}$  are the lower bound and upper bound of the interval  $[d_{A-B}^{L\alpha}, d_{A-B}^{R\alpha}]$  respectively, resulting from the  $\alpha$  cut on  $D_{A-B}$  ( $0 \leq \alpha \leq 1$ ).  $A$  dominates  $B$  if  $d(A-B) > 0$ , and  $A$  is dominated by  $B$  if  $d(A-B) < 0$ . The larger the value of  $d(A-B)$ , the higher the degree of dominance of  $A$  over  $B$ .

To apply the degree of dominance concept, a common comparison base needs to be established with respect to the weighted fuzzy performance matrix in (5.5). To achieve this, the concept of the fuzzy maximum and the fuzzy minimum (Chen, 1985) is applied. Given the fuzzy vector  $(w_j x_{1j}, w_j x_{2j}, \dots, w_j x_{mj})$  of the weighted fuzzy performance matrix for criterion  $C_j$ , a fuzzy maximum ( $M_{\max}^j$ ) and a fuzzy minimum ( $M_{\min}^j$ ) can be determined as in (5.10) - (5.11) which represent respectively the best and the worst fuzzy performance ratings among all the alternatives with respect to criterion  $C_j$ .

$$\mu_{M_{\max}^j}(x) = \begin{cases} \frac{x - x_{\min}^j}{x_{\max}^j - x_{\min}^j}, & x_{\min}^j \leq x \leq x_{\max}^j, \\ 0, & \end{cases} \quad (5.10)$$

$$\mu_{M_{\min}^j}(x) = \begin{cases} \frac{x_{\max}^j - x}{x_{\max}^j - x_{\min}^j}, & x_{\min}^j \leq x \leq x_{\max}^j, \\ 0, & \end{cases} \quad (5.11)$$

where  $i = 1, 2, \dots, n$ ;  $j = 1, 2, \dots, m$ ;  $x_{\max}^j = \sup \bigcup_{i=1}^n \{x \in R \text{ and } 0 < \mu_{w_j x_{ij}}(x) < 1\}$ , and

$$x_{\min}^j = \inf \bigcup_{i=1}^n \{x \in R \text{ and } 0 < \mu_{w_j x_{ij}}(x) < 1\}.$$



The degree to which the fuzzy maximum dominates the weighted fuzzy performance ( $w_j x_{ij}$ ) of alternative  $A_i$  with respect to criterion  $C_j$  can be calculated as

$$d_{ij}^+ = d(M_{\max}^j - w_j x_{ij}) = \int D_{(M_{\max}^j - w_j x_{ij})}(\alpha) d\alpha \quad (5.12)$$

where

$$D_{M_{\max}^j - w_j x_{ij}}(\alpha) = \begin{cases} \frac{d_{(M_{\max}^j - w_j x_{ij})}^{L\alpha} + d_{(M_{\max}^j - w_j x_{ij})}^{R\alpha}}{2}, & 0 \leq \alpha \leq 1, \\ 0, & \text{otherwise.} \end{cases} \quad (5.13)$$

Similarly, the degree of dominance of the weighted fuzzy performance ( $w_j x_{ij}$ ) of alternative  $A_i$  over the fuzzy minimum with respect to criterion  $C_j$  is given as

$$d_{ij}^- = d(w_j x_{ij} - M_{\min}^j) = \int D_{(w_j x_{ij} - M_{\min}^j)}(\alpha) d\alpha \quad (5.14)$$

where

$$D_{(w_j x_{ij} - M_{\min}^j)}(\alpha) = \begin{cases} \frac{d_{(w_j x_{ij} - M_{\min}^j)}^{L\alpha} + d_{(w_j x_{ij} - M_{\min}^j)}^{R\alpha}}{2}, & 0 \leq \alpha \leq 1, \\ 0, & \text{otherwise.} \end{cases} \quad (5.15)$$

To calculate the overall performance index for each alternative across all criteria, the concept of ideal solutions is applied. Based on the concept of ideal solutions, the positive fuzzy ideal solution consists of the fuzzy maximum with respect to each criterion across all alternatives, and the negative fuzzy ideal solution consists of the fuzzy minimum in regard to each criterion across all alternatives (Chang and Yeh, 2004; Yeh and Deng, 2004). The degree of dominance that the positive fuzzy ideal solution is on each alternative  $A_i$  and the degree of dominance that each alternative  $A_i$  has on the negative fuzzy ideal solution can be calculated respectively as

$$d_i^+ = \sum_{j=1}^m d_{ij}^+ \quad (5.16)$$

$$d_i^- = \sum_{j=1}^m d_{ij}^- \quad (5.17)$$

An alternative is preferred if it is dominated by the positive fuzzy ideal solution by a smaller degree, and at the same time dominates the negative fuzzy ideal solution by a larger degree (Yeh and Deng, 2004). Based on this notion, an overall performance index for each alternative  $A_i$  across all criteria is calculated as

$$P_i = \frac{(d_i^-)^2}{(d_i^+)^2 + (d_i^-)^2} \quad (5.18)$$

The larger the performance index  $P_i$ , the more preferred the alternative  $A_i$ .

The approach presented above can be summarized as follows:

- Step 1. Obtain the fuzzy decision matrix for each decision maker, as expressed in (5.1).
- Step 2. Obtain the weighting vector of each decision maker for the criteria, as expressed in (5.2).
- Step 3. Obtain the overall fuzzy decision matrix and the overall fuzzy weighting vector by (5.3) and (5.4) respectively.
- Step 4. Obtain the weighted fuzzy performance matrix by multiplying the overall fuzzy decision matrix (5.3) and the overall fuzzy weighting vector (5.4) given as in (5.5).
- Step 5. Determine the fuzzy maximum which represents the best fuzzy performance ratings among all the alternatives as the positive fuzzy ideal solution by (5.10)

- Step 6. Determine the fuzzy minimum which represents the worst fuzzy performance ratings among all the alternatives as the negative fuzzy ideal solution by (5.11).
- Step 7. Calculate the degree of dominance that the positive fuzzy ideal solution has on each alternative by (5.12), (5.13), and (5.16).
- Step 8. Calculate the degree of dominance that each alternative has on the negative fuzzy ideal solution by (5.14), (5.15) and (5.17).
- Step 9. Compute the overall performance index value for each alternative by (5.18).
- Step 10. Rank the alternatives in descending order of their performance index values.

### **5.3 A Multicriteria Decision Support System**

To help the decision makers solve the multicriteria group decision making problem in a user-friendly manner, a multicriteria DSS is presented. The multicriteria DSS allows the decision makers to input values to express their preferences and assessments and to examine the relationships between the evaluation criteria, and the available alternatives and the selection outcome. Through interaction, the multicriteria DSS helps the decision makers adopt a problem-oriented approach for solving the multicriteria group decision making problem effectively and efficiently.

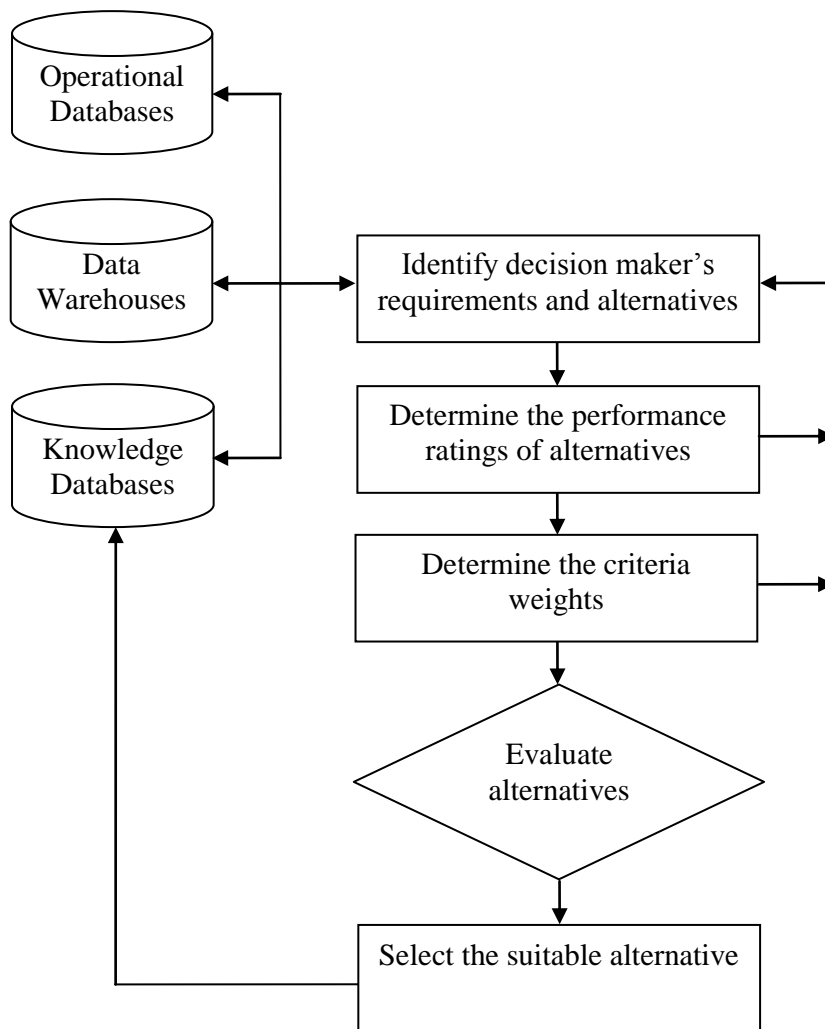
The proposed multicriteria DSS is composed of four main components: (a) the data management sub-system, (b) the model base sub-system, (c) the knowledge management sub-system, and (d) the dialogue sub-system. The data management sub-system contains pre-

defined connections to internal and external data repositories. This sub-system is responsible for providing data required by other system components. For example, when a decision maker requires specific information about a particular alternative, the data management system will coordinate the acquisition and delivery of the summarized data in the required format. The model base sub-system includes the multicriteria group decision making algorithm presented in the previous section. This sub-system may include other analytical tools to analyze and evaluate alternatives. The knowledge management sub-system help the decision makers identify decision alternatives and make assessments. It is inter-connected with the company's knowledge base comprising of IF-THEN rules. The dialogue sub-system provides a user friendly interface for the decision makers to communicate with the multicriteria DSS.

Using the proposed multicriteria DSS to select alternatives involves three phases, including (a) pre-evaluation, (b) preference elicitation, and (c) decision analysis and reporting, as shown in Figure 5.1. The pre-evaluation phase is used to identify the requirements of the selection problem and to determine the alternatives. The preference elicitation phase is used to define individual linguistic terms and the corresponding triangular fuzzy numbers, and to determine the criteria weights and performance ratings of alternatives. In determining the criteria weights, the decision makers can carry out sensitive analysis on weights and examine their effects on the outcome. In practical applications, all the assessments with respect to criteria weights and alternative performance are not always fuzzy. This is because the criteria may include both quantitative and qualitative measures that satisfy the requirements of the selection problem and the judgments of the decision makers (Deng and Wibowo, 2008). As such, both crisp and fuzzy data are often present simultaneously in a specific multicriteria selection problem (Deng, 2005).

The criteria weight and performance ratings of alternatives can be assessed by a crisp value or using a linguistic term, depending on the preference or judgment of the decision makers. To maintain the consistence of assessment data in both crisp and fuzzy forms, the decision makers' quantitative assessments are made using a crisp value in the range of 1 to 9. To make qualitative assessments, the decision makers use a set of linguistic terms. The decision makers can use the default settings given in Table 5.1 or define their own term set from the universe  $U = \{\text{excellent, very high, high to very high, high, fairly high, medium, fairly low, low, low to very low, very low, none}\}$ , which is available from the knowledge base of the multicriteria DSS. The decision makers also have the option of defining the value range or the membership function of triangular fuzzy numbers to be used for representing the linguistic terms in their assessments. The DSS enables the decision makers to make both quantitative and qualitative assessments, because the multicriteria group decision making algorithm developed in this chapter for solving the multicriteria group decision making problem can handle both crisp and fuzzy assessment data.

In the decision analysis and reporting phase, the multicriteria group decision making algorithm is applied to evaluate and select the most suitable alternative. The overall performance index value of each alternative, relative to other alternatives, is obtained by aggregating the criteria weights and its performance ratings using the algorithm. Based on the overall performance index value and ranking of all alternatives, the most suitable alternative can be recommended in a rational and justifiable manner.



**Figure 5.1 The Decision Support System Framework for Multicriteria Group Decision Making**

## 5.4 Concluding Remarks

Solving the multicriteria group decision making problem is a complex process as it involves multiple decision makers making subjective and imprecise assessments in relation to multiple decision alternatives and evaluation criteria. To ensure effective decision outcomes are being

made, it is important to effectively address the needs of multiple decision makers and multiple criteria, (b) adequately model the subjectiveness and imprecision of the human decision making process, and (c) reduce cognitive demand on the decision makers in the process.

This chapter has presented an effective DSS based approach for solving the multicriteria group decision making problem. The approach is capable of effectively handling the subjectiveness and imprecision associated with the human decision making process respectively by considering the decision makers' subjective assessments in the multicriteria group decision making process. As a consequence, effective decisions can be made based on the proper consideration of the decision makers' subjective assessments.

## **Chapter 6**

# **A Consensus Based Approach for Multicriteria Group Decision Making**

### **6.1 Introduction**

Dealing with multicriteria group decision making problems is complex and challenging as previously explained in Chapter 5. In addition to the complex and challenging issues associated with multicriteria group decision making, the major challenge in solving the multicriteria group decision making problem is how to obtain a compromise solution that will best satisfy all the decision makers involved. To ensure that a compromise solution is achieved, a certain level of consensus or agreement among multiple decision makers has to be reached (Sreekumar and Mahapatra, 2009; Wibowo and Deng, 2009).

A consensus decision is the one when most decision makers in the group agree on a clear option and the few who oppose it believe that they have had a reasonable opportunity to influence that choice (Herrera-Viedma et al., 2005). Developing consensus in multicriteria group decision making is complicated due to the fact that (a) decision makers may not share the same opinion about the alternatives, (b) they may express their opinion or preferences in a subjective or imprecise manner, and (c) the group decision making process is cognitively demanding on the decision makers (Muralidharan et al., 2002; Herrera-Viedma et al., 2005;



Ben-Arieh and Chen, 2006; Sreekumar and Mahapatra, 2009). It is therefore desirable to have a structured approach for addressing these concerns in multicriteria group decision making.

The purpose of this chapter is to address the Decision Context C described in Chapter 3 by the development of a consensus based approach for effectively solving the multicriteria group decision making problem. A consensus building algorithm is developed for solving the multicriteria group decision making problem. A DSS is proposed incorporating the proposed consensus building algorithm for facilitating the consensus building process in solving the multicriteria group decision making problem.

In what follows, a review on consensus building in group decision making is presented first. This is followed by the development of a consensus building algorithm for solving the multicriteria group decision making problem. The DSS is then presented for facilitating the consensus building process in multicriteria group decision making.

## **6.2 Consensus Building in Group Decision Making**

Recognizing the importance of reaching an agreement among decision makers, much research has been done on the development of many approaches for consensus based decision making (Herrera-Viedma et al., 2005; Lo et al., 2005; Xu, 2005; Choudhury et al., 2006; Ben-Arieh and Easton, 2007; Giordano et al., 2007; Cabrerizo et al., 2009).

In general, consensus building is generally classified into (a) hard consensus and (b) soft consensus (Herrera-Viedma et al., 2005). The hard consensus represents the consensus

measures of interval  $[0, 1]$  where 0 indicates there is no agreement and 1 indicates a full agreement among the decision makers. The soft consensus allows the decision makers to reach a consensus when most of the decision makers involved in the group decision making process agree on their preferences. This allows decision makers to assess their opinions in a more flexible manner (Lo et al., 2005). Obtaining an absolute consensus using hard consensus is almost impossible to achieve (Herrera-Viedma et al., 2005; Xu, 2005). This is due to the inherent subjectiveness and imprecision in group decision making. As a result, soft consensus building is desirable for solving the group decision making problem in real situations.

Herrera-Viedma et al. (2005), for example, present a consensus building approach for group decision making based on the distance between the individual opinions and the group opinion. A linguistic consensus degree based on the linguistic distances is defined. The linguistic distance is used to indicate how far each individual is from the current consensus level. Based on this information, the decision makers can perform a negotiation process to reach an acceptable consensus outcome. The approach, however, is still far from satisfaction in tackling the group decision making problem due to its inability to provide recommendations to the specific decision makers on the level of change of their assessments for obtaining the maximum level of consensus agreement.

Lo et al. (2005) develop an approach for measuring the consensus among decision makers. A similarity measure is introduced to attain the consensus interval of the group via the agreement matrix for a group decision making problem. The proposed approach analyses the trend of group consensus using the similarity measures for calculating the consensus index. The approach is found to be useful in dealing with situations involving vague and ill-defined

data. It however requires complicated mathematical computation, and is very demanding cognitively on the decision makers in the evaluation process (Wibowo and Deng, 2009).

Xu (2005) applies a ranking approach for reaching the consensus among multiple decision makers. The developed approach first aggregates individual decision matrices into a group decision matrix by using the additive weighted aggregation operator. An iterative algorithm is then developed for gaining a consentaneous group decision matrix. Based on the consentaneous group decision matrix, an overall performance value for each alternative across all criteria can be obtained, on which the most desirable alternative can be selected. The approach is practical for reaching consensus among group opinions. It, however, is incapable of taking into account the decision makers' right to modify their opinions.

The discussion above shows that existing approaches to consensus building are useful in dealing with the multicriteria group decision making problem. These approaches, however, have various shortcomings including (a) requirement of complicated mathematical computation, (b) inability to handle the subjectiveness and imprecision in the evaluation process, (c) cognitive demand on the decision makers, and (d) lack of flexibility in fulfilling the requirements of the decision makers. To help address this challenging issue in consensus building, it is therefore desirable to have a structured decision making process that can incorporate a consensus building algorithm for effectively solving the multicriteria group decision making problem.

### 6.3 A Consensus Building Algorithm

Multicriteria group decision making involves in evaluating and selecting alternatives with respect to multiple, often conflicting criteria with the participation of multiple decision makers (Yeh et al., 2010). A multicriteria group decision making problem usually involves in (a) discovering all the alternatives, (b) identifying the selection criteria, (c) assessing the alternatives' performance ratings and the criteria weights through a consensus building process, (d) aggregating the alternative ratings and criteria weights for producing an overall performance index for each alternative across all the criteria, and (e) selecting the best alternative in the given situation (Chen and Chen, 2004; Wibowo and Deng, 2009; Yeh et al., 2010).

The proposed consensus building algorithm is designed to provide a systematic and effective manner to multicriteria evaluation and selection involving multiple decision makers. The evaluation and selection process starts with the determination of the performance of each alternative  $A_i$  ( $i = 1, 2, \dots, n$ ) with respect to each criterion  $C_j$  ( $j = 1, 2, \dots, m$ ) by individual decision makers  $D_k$  ( $k = 1, 2, \dots, s$ ). As a result, a decision matrix for the multicriteria group decision making problem for each decision maker can be expressed as:

$$Y^k = \begin{bmatrix} y_{11}^k & y_{12}^k & \cdots & y_{1m}^k \\ y_{21}^k & y_{22}^k & \cdots & y_{2m}^k \\ \cdots & \cdots & \cdots & \cdots \\ y_{n1}^k & y_{n2}^k & \cdots & y_{nm}^k \end{bmatrix}; \quad k = 1, 2, \dots, s. \quad (6.1)$$

where  $y_{ij}^k$  is the fuzzy assessment of the decision maker,  $D_k$  ( $k = 1, 2, \dots, s$ ) about the performance rating of alternative  $A_i$  with respect to criterion  $C_j$ .

The relative importance of the selection criteria  $C_j$  can be assessed qualitatively by each  $D_k$  ( $k = 1, 2, \dots, s$ ) using fuzzy numbers, given as

$$w^k = (w_1^k, w_2^k, \dots, w_m^k); k = 1, 2, \dots, s \quad (6.2)$$

By averaging the fuzzy assessments made by individual decision makers as given in (6.1) and (6.2), the overall fuzzy decision matrix and the fuzzy weight vector for the problem of multicriteria evaluation and selection of alternatives involving multiple decision makers can be obtained as

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (6.3)$$

$$W = (w_1, w_2, \dots, w_m) \quad (6.4)$$

where  $x_{ij} = \frac{\sum_{k=1}^s y_{ij}^k}{s}$  and  $w_j = \frac{\sum_{k=1}^s w_j^k}{s}$ .

To understand the degree of consensus among the decision makers, the concept of similarity is introduced. This concept of similarity measures the degree of consensus among the decision makers by calculating the distance of individual decision makers' opinion to the group opinion. This similarity measure is beneficial towards consensus building process as the value obtained from the similarity measure is used to guide the decision makers in the direction of the changes in their opinions in order to increase the consensus level.

Several similarity measures have been proposed (Chen and Chen, 2004; Xu, 2005; Wei and Chen, 2009) for dealing with specific decision making problems. However, there are limitations with the existing measures including (a) the requirement of complicated

mathematical computation and (b) the cognitive demanding on the decision makers. In this chapter, the degree of similarity measure using the vertex method (Chen, 2000) is introduced for calculating the distance between two triangular fuzzy numbers. This is due to its simplicity in concept, and efficiency in computation. Thus, the degree of similarity between individual decision makers' fuzzy assessments and the group fuzzy assessments for the performance ratings on each criterion is obtained as

$$S_{ij}^k = 1 - \left( \frac{(y_{ij(L)}^k - x_{ij(L)}) + (y_{ij(M)}^k - x_{ij(M)}) + (y_{ij(R)}^k - x_{ij(R)})}{3} \right) \quad (6.5)$$

where  $y_{ij(L)}^k$ ,  $y_{ij(M)}^k$ , and  $y_{ij(R)}^k$  represent the lower bound, middle bound, and upper bound of individual decision maker's assessments, and  $x_{ij(L)}$ ,  $x_{ij(M)}$ , and  $x_{ij(R)}$  are the lower bound, middle bound, and upper bound of the group assessments about the performance rating of alternative  $A_i$  with respect to criterion  $C_j$  respectively.

Similarly, the degree of similarity between individual decision makers' fuzzy assessments and the group fuzzy assessments for the criteria weights with respect to each criterion is

$$T_j^k = 1 - \left( \frac{(w_{j(L)}^k - w_{j(L)}) + (w_{j(M)}^k - w_{j(M)}) + (w_{j(R)}^k - w_{j(R)})}{3} \right) \quad (6.6)$$

where  $w_{j(L)}^k$ ,  $w_{j(M)}^k$ , and  $w_{j(R)}^k$  represent the lower bound, middle bound, and upper bound of individual decision maker's assessments, and  $w_{j(L)}$ ,  $w_{j(M)}$ , and  $w_{j(R)}$  represent the lower bound, middle bound, and upper bound of group assessments about the criteria weight of alternative  $A_i$  respectively.

To ensure the level of agreement between the decision maker's preferences is consistent, a consistency index (CI) is established. This CI value is used to identify whether the

preferences provided by individual decision makers are of acceptable consistency to the specified consensus threshold pre-determined by the group decision makers. This is done by allocating an agreed CI value by the group decision makers and by comparing the agreed group value to the calculated value of an individual decision maker. If the CI value of an individual decision maker is lower than the specified consensus threshold, the decision maker concerned has to adjust his/her assessments. This process is a consensus building process as it continuously requests decision makers to modify their assessments until all the CI values of individual decision makers are higher than the specified consensus threshold. The CI for the group in regards to the performance ratings and the criteria weights for all alternatives across the criteria can be defined as

$$CI = \max (S_{ij}^k, T_j^k) \quad (6.7)$$

The larger the value of CI, the more consistent the individual decision makers' preferences to the group preference. If the CI value of a specific decision maker is lower than the specified consensus threshold assigned by the decision makers', the decision maker concerned needs to modify his/her assessments in order to improve the group consensus level. This concept is used as a feedback mechanism to guide the DSS system in the direction of the changes in the decision makers' opinions in order to increase the consensus level (Chen and Chen, 2004; Xu, 2005; Wibowo and Deng, 2009).

The procedure for achieving group consensus using the consensus building algorithm is summarized as

- Step 1. Obtain the decision matrix for each decision maker as expressed in (6.1).
- Step 2. Determine the weighting vector of each decision maker for the criteria as expressed in (6.2).

- Step 3. Determine the overall fuzzy decision matrix for the decision makers by averaging the fuzzy assessments made by individual decision makers as given in (6.1).
- Step 4. Determine the fuzzy weight vector for the decision makers by averaging the fuzzy assessments made by individual decision makers as given in (6.2).
- Step 5. Calculate the degree of similarity between individual decision makers' fuzzy assessments and the group fuzzy assessments for the performance ratings with respect to each criterion using (6.5).
- Step 6. Calculate the degree of similarity between individual decision makers' fuzzy assessments and the group fuzzy assessments for the criteria weights with respect to each criterion by (6.6).
- Step 7. Obtain the CI value for individual decision makers by (6.7). If the value of CI of any decision maker is less than the pre-defined threshold value, then the decision maker concerned needs to go back to Step 1 and change his/her assessments. Otherwise, the consensus building process is finalized.

Once the consensus building process is finalized, the weighted fuzzy performance matrix that represents the overall performance of each alternative on each criterion can be determined by multiplying the fuzzy criteria weights by the alternatives' fuzzy performance ratings. Given the fuzzy vector  $(w_j x_{1j}, w_j x_{2j}, \dots, w_j x_{mj})$  of the weighted fuzzy performance matrix for criterion  $C_j$ , a fuzzy maximum  $(M_{\max}^j)$  and a fuzzy minimum  $(M_{\min}^j)$  can be determined as in (6.8)-(6.9) representing respectively the best and the worst fuzzy performance ratings among all the alternatives with respect to criterion

$$\mu_{M_{\max}^j}(x) = \begin{cases} \frac{x - x_{\min}^j}{x_{\max}^j - x_{\min}^j}, & x_{\min}^j \leq x \leq x_{\max}^j, \\ 0, & \text{otherwise} \end{cases} \quad (6.8)$$



$$\mu_{M_{\min}^j}(x) = \begin{cases} \frac{x_{\max}^j - x}{x_{\max}^j - x_{\min}^j}, & x_{\min}^j \leq x \leq x_{\max}^j, \\ 0, & \text{otherwise} \end{cases} \quad (6.9)$$

where  $i = 1, 2, \dots, n$ ;  $j = 1, 2, \dots, m$ ;  $x_{\max}^j = \sup \bigcup_{i=1}^n \{x \in R \text{ and } 0 < \mu_{w_j x_{ij}}(x) < 1\}$ , and

$$x_{\min}^j = \inf \bigcup_{i=1}^n \{x \in R \text{ and } 0 < \mu_{w_j x_{ij}}(x) < 1\}.$$

The degree to which alternative  $A_i$  is the best alternative with respect to criterion  $C_j$  can then be calculated by comparing its weighted fuzzy performance ( $w_j x_{ij}$ ) with the fuzzy maximum ( $M_{\max}^j$ ), given as in (6.10).  $u_{Rj}(i)$  represents the highest degree of approximation of alternative  $A_i$ 's weighted performance on criterion  $C_j$  to the fuzzy maximum given as

$$\mu_{Rj}(i) = \sup_{x \in R} \mu_{w_j x_{ij} \cap M_{\max}^j} \quad (6.10)$$

Similarly, the degree to which alternative  $A_i$  is not the worst alternative with respect to criterion  $C_j$  can be calculated by comparing the weighted fuzzy performance ( $w_j x_{ij}$ ) of supplier  $A_i$  with the fuzzy minimum ( $M_{\min}^j$ ), given as

$$\mu_{Lj}(i) = 1 - \sup_{x \in R} \mu_{w_j x_{ij} \cap M_{\min}^j} \quad (6.11)$$

The degree of optimality (or preferability) of alternative  $A_i$  over all other alternatives with respect to criterion  $C_j$  is thus determined by

$$r_{ij} = \frac{1}{2} ((u_{Rj}(i) + u_{Lj}(i))), \quad (6.12)$$

A fuzzy singleton matrix can be obtained from the weighted fuzzy performance matrix based on (6.8)-(6.12), given as

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix} \quad (6.13)$$

To rank all the alternatives, the concept of the positive and negative ideal solutions is used. The positive (or negative) ideal solution consists of the best (or worst) values attainable from all the alternatives (Chen, 2000; Deng et al., 2000). The most preferred alternative should not only have the shortest distance from the positive ideal solution, but also have the longest distance from the negative ideal solution (Zeleny, 1982). Based on the concept of the ideal solution, the positive ideal solution  $A^+$  and the negative ideal solution  $A^-$  can be determined as

$$A^+ = (a_1^+, a_2^+, \dots, a_m^+), \quad A^- = (a_1^-, a_2^-, \dots, a_m^-), \quad (6.14)$$

$$\text{where } a_j^+ = \sup(r_{1j}, r_{2j}, \dots, r_{nj}), \quad a_j^- = \inf(r_{1j}, r_{2j}, \dots, r_{nj}), \quad (6.15)$$

From (6.13) to (6.15), the Hamming distance between alternative  $A_i$  and the positive ideal solution and the negative solution can be calculated respectively as

$$s_i^+ = \sum_{j=1}^m (a_j^+ - r_{ij}), \quad s_i^- = \sum_{j=1}^m (r_{ij} - a_j^-), \quad (6.16)$$

where  $i = 1, 2, \dots, n$ .  $j = 1, 2, \dots, m$ .

As a result, an overall performance index  $P_i$  for each alternative  $A_i$  across all the criteria can be determined by (6.17). The larger the  $P_i$ , the more preferred the alternative  $A_i$ .

$$P_i = \frac{s_i^-}{s_i^+ + s_i^-} \quad (6.17)$$

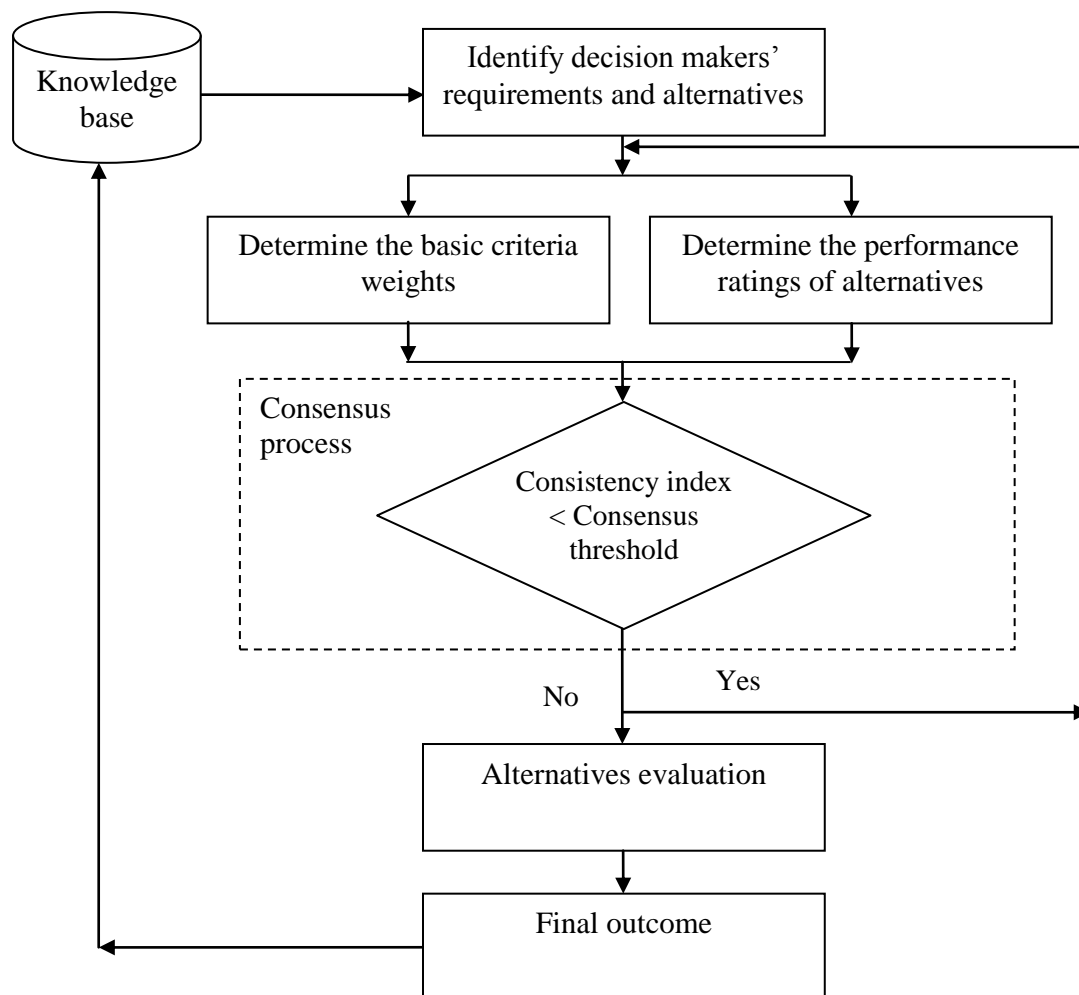
## 6.4 A Decision Support System

To assist decision makers in solving the multicriteria group decision making problem in an efficient and effective manner, a DSS is presented in this section. The DSS is composed of four main modules including (a) the knowledge base module, (b) the model base module, (c), the database module, and (d) the user interface module (Deng and Wibowo, 2008; Wibowo and Deng, 2009). The knowledge management module helps the decision makers identify the alternatives and make assessments. It is inter-connected with the company's knowledge base comprising of IF–THEN rules. The model base module includes the consensus building algorithm. This module may include other analytical tools to analyze and evaluate alternatives. The database module mainly contains a relational database to provide fast data retrieval, updating and editing. The user interface provides the means for the user to interface with the DSS.

The proposed DSS for facilitating the consensus building process in multicriteria group decision making comprises of six stages, namely (a) problem definition, (b) criteria definition, (c) alternatives' pre-qualification, (d) consensus measurement, (e) alternatives' evaluation, and (f) final selection as shown in Figure 6.1 (Wibowo and Deng, 2009).

The problem definition stage is used to identify the requirements of decision makers and all available alternatives. The criteria definition stage is used to define all relevant criteria for alternative selection process. The alternatives' pre-qualification stage is used to define individual linguistic terms, determine the performance ratings of alternatives and criteria weight of individual decision makers, and propose the agreed consensus threshold.

The consensus measurement stage is used to measure the degree of consensus among decision makers' opinions. In this stage, the degree of similarities and the CI value between individual decision makers' fuzzy assessments and the group fuzzy assessments are calculated. If the CI value of an individual decision maker is lower than the specified consensus threshold, the system instructs the decision maker concerned to modify his/her assessments. The system will continue to iteratively measure the CI value until all the CI values of individual decision makers are higher than the specified consensus threshold.



**Figure 6.1 The Decision Support System Framework**

In the alternatives' evaluation stage, the consensus building algorithm is selected for evaluating and selecting the most suitable alternative. The performance index of each alternative is obtained by aggregating the criteria weights and its performance ratings. Based on the overall performance index values and rankings of all alternatives, the most suitable alternative is recommended to the decision makers. This leads to effective decisions being made based on the recommendation by the DSS.

## **6.5 Concluding Remarks**

Developing consensus in multicriteria group decision making is complex and challenging as it involves in several decision makers, multiple selection criteria, and the presence of subjective and imprecise assessments in the group decision making process. To ensure effective decision outcomes, it is important to adequately consider the interest of different stakeholders in the group decision making process.

This chapter has presented a consensus based approach for effectively solving the multicriteria group decision making problem. A consensus building algorithm is developed for solving the multicriteria group decision making problem. A DSS is proposed for incorporating the proposed consensus building algorithm for evaluating and selecting appropriate alternatives in a given situation. This consensus based approach is capable of effectively and efficiently handling the group decision making process in the multicriteria group decision making problem.

## **Chapter 7**

### **Risk-Oriented Decision Making for Multicriteria**

#### **Group Decision Making under Uncertainty**

##### **7.1 Introduction**

Risk is the probability and severity of an undesirable event (Fenton and Wang, 2006; Ritchie and Brindley, 2007). It is present due to the subjectiveness and imprecision inherent in the human decision making process (Zimmermann, 2000; Lam et al., 2007). The subjectiveness and imprecision is originated from (a) incomplete information, (b) abundant information, (c) conflicting evidence, (d) ambiguous information, and (e) subjective information in the human decision making process (Deng and Wibowo, 2008; Samson et al., 2009; Yeh et al., 2010).

Multicriteria group decision making is concerned with evaluating and selecting alternatives with respect to multiple, often conflicting criteria involving multiple decision makers in a given situation (Shih et al., 2005; Yeh et al., 2010). To ensure effective decision outcomes are made by multiple decision makers, it is important to effectively modelling the subjectiveness and imprecision inherent in the decision making process. This is due to the fact that decision makers' attitudes towards risk usually have a major effect on their decision behaviors, often resulting in different decisions being made (Wang and Elhag, 2006; Chen and Wang, 2009; Wibowo and Deng, 2009). Effective decision making therefore requires an appropriate

consideration of the potential risk in a specific decision making situation (Lam et al., 2007; Ritchie and Brindley, 2007; Wibowo and Deng, 2010a).

The purpose of this chapter is to address the Decision Context D as outlined in Chapter 3 by the development of a risk-oriented approach for adequately modelling the inherent risk in the multicriteria group decision making process under uncertainty. Linguistic variables approximated by triangular fuzzy numbers are used for representing the uncertain and imprecise assessments of the decision makers in evaluating the relative importance of the evaluation criteria and the performance of alternatives. To avoid the complicated and unreliable process of comparing and ranking fuzzy utilities often required in fuzzy multicriteria analysis, the concept of the ideal solution is introduced for calculating an overall performance index for each alternative across all criteria.

In what follows, a risk-oriented approach is presented to show its implementation ability for adequately modelling the inherent risk in solving practical multicriteria group decision making problems under uncertainty.

## **7.2 A Risk-Oriented Approach**

Multicriteria group decision making involves in evaluating and selecting alternatives with respect to multiple, often conflicting criteria with the participation of multiple decision makers in a given situation (Yeh et al., 2010). The multicriteria group decision making process usually consists of (a) discovering all the alternatives, (b) identifying the selection criteria, (c) assessing the performance rating of alternatives and the weight of criteria, (d)

aggregating the alternative ratings and criteria weights for producing an overall performance index for each alternative across all the criteria, and (e) selecting the best alternative in the given situation (Yeh et al., 2009 Wibowo and Deng, 2010b).

The multicriteria group decision making process starts with assessing the performance rating of each decision alternative  $A_i$  ( $i = 1, 2, \dots, n$ ) with respect to each criterion  $C_j$  ( $j = 1, 2, \dots, m$ ), by each decision makers  $D_k$  ( $k = 1, 2, \dots, s$ ). As a result,  $s$  decision matrices for the multicriteria group decision making problem can be expressed as follows

$$Y^k = \begin{bmatrix} y_{11}^k & y_{12}^k & \dots & y_{1m}^k \\ y_{21}^k & y_{22}^k & \dots & y_{2m}^k \\ \dots & \dots & \dots & \dots \\ y_{n1}^k & y_{n2}^k & \dots & y_{nm}^k \end{bmatrix}; \quad k = 1, 2, \dots, s. \quad (7.1)$$

where  $y_{ij}^k$  is the fuzzy assessment of the decision maker,  $D_k$  ( $k = 1, 2, \dots, s$ ) about the performance rating of alternative  $A_i$  with respect to criterion  $C_j$ .

The relative importance of the selection criteria  $C_j$  can be assessed qualitatively by each  $D_k$  ( $k = 1, 2, \dots, s$ ), given as

$$w^k = (w_1^k, w_2^k, \dots, w_m^k); \quad k = 1, 2, \dots, s. \quad (7.2)$$

The weighted fuzzy performance matrix that represents the overall performance of each alternative on each criterion for each decision maker can then be determined by multiplying the fuzzy criteria weights  $w_j^k$  by the alternatives' fuzzy performance ratings  $y_{ij}^k$  as

$$Z^k = \begin{bmatrix} w_1^k y_{11}^k & w_2^k y_{12}^k & \dots & w_m^k y_{1m}^k \\ w_1^k y_{21}^k & w_2^k y_{22}^k & \dots & w_m^k y_{2m}^k \\ \dots & \dots & \dots & \dots \\ w_1^k y_{n1}^k & w_2^k y_{n2}^k & \dots & w_m^k y_{nm}^k \end{bmatrix}, \quad (7.3)$$



To reflect on the decision makers' attitude towards risk in the decision making process, the idea of incorporating the risk involved in the decision makers' subjective assessments is introduced. This is beneficial towards the decision making process as the ability of decision makers to (a) adequately deal with subjectiveness and imprecision and (b) handle the risk inherent in the decision making process that will help increase the confidence of the decision makers (Deng, 2005; Wibowo and Deng, 2010a).

To address this issue,  $\lambda (0 \leq \lambda \leq 1)$  is introduced for reflecting the decision makers' attitude towards risk in approximating their subjective assessments. A larger  $\lambda$  value indicates that the decision maker's assessments are closer to the most possible value  $a_2$  of the triangular fuzzy number  $(a_1, a_2, a_3)$ . Based on this concept, the refined assessment of individual decision makers in regards to their attitudes towards risk is defined as

$$z_{ij}^{k\lambda} = (a_1 + \lambda(a_2 - a_1), a_2, a_3 - \lambda(a_3 - a_2)) \quad (7.4)$$

where  $a_1$ ,  $a_2$ , and  $a_3$  are the lower bound, middle bound, and upper bound of individual decision makers' assessments about the performance rating of alternative  $A_i$  with respect to criterion  $C_j$  respectively.

In practical applications,  $\lambda = 1$ ,  $0.5$ , or  $0$  can be used respectively to indicate that the decision maker involved has an optimistic, moderate, or pessimistic view in the selection process (Yeh et al., 2000). An optimistic decision maker is apt to prefer higher values of his/her fuzzy assessments, while a pessimistic decision maker tends to favor lower values (Yeh et al., 2000; Deng, 2005).

Having already incorporated the individual decision makers' attitude towards risk as in (7.4), the fuzzy performance matrix for individual decision makers can be obtained as

$$Z^{k\lambda} = \begin{bmatrix} z_{11}^{k\lambda} & z_{12}^{k\lambda} & \dots & z_{1m}^{k\lambda} \\ z_{21}^{k\lambda} & z_{22}^{k\lambda} & \dots & z_{2m}^{k\lambda} \\ \dots & \dots & \dots & \dots \\ z_{n1}^{k\lambda} & z_{n2}^{k\lambda} & \dots & z_{nm}^{k\lambda} \end{bmatrix}, \quad (7.5)$$

By averaging the fuzzy assessments made by individual decision makers as given in (7.5), the overall fuzzy group performance matrix can be obtained as

$$Z^\lambda = \begin{bmatrix} z_{11}^\lambda & z_{12}^\lambda & \dots & z_{1m}^\lambda \\ z_{21}^\lambda & z_{22}^\lambda & \dots & z_{2m}^\lambda \\ \dots & \dots & \dots & \dots \\ z_{n1}^\lambda & z_{n2}^\lambda & \dots & z_{nm}^\lambda \end{bmatrix}, \quad (7.6)$$

Given the fuzzy vector of the performance matrix for criterion  $C_j$ , a fuzzy maximum ( $M_{\max}^j$ ) and a fuzzy minimum ( $M_{\min}^j$ ) (Chen, 1985) can be determined as in (7.7)-(7.8) which represent respectively the best and the worst fuzzy performance ratings among all the alternatives with respect to criterion  $C_j$  (Zadeh, 1973; Chen, 1985).

$$\mu_{M_{\max}^j}(z^\lambda) = \begin{cases} \frac{z^\lambda - z_{\min}^{\lambda j}}{z_{\max}^{\lambda j} - z_{\min}^{\lambda j}}, \\ 0, \end{cases} \quad (7.7)$$

$$\mu_{M_{\min}^j}(z^\lambda) = \begin{cases} \frac{z_{\max}^{\lambda j} - z^\lambda}{z_{\max}^{\lambda j} - z_{\min}^{\lambda j}}, \\ 0, \end{cases} \quad (7.8)$$

where  $i = 1, 2, \dots, n; j = 1, 2, \dots, m$ .

$$z_{\max}^{\lambda j} = \sup \bigcup_{i=1}^n (z_{ij}^\lambda), \quad (7.9)$$

$$z_{\min}^{\lambda j} = \inf \bigcup_{i=1}^n (z_{ij}^\lambda). \quad (7.10)$$

The degree to which alternative  $A_i$  is the best alternative with respect to criterion  $C_j$  can then be calculated by comparing its weighted fuzzy performance ( $z_{ij}^\lambda$ ) with the fuzzy maximum ( $M_{\max}^j$ ), given as in (7.11).  $u_{R_j}(i)$  represents the highest degree of approximation of alternative  $A_i$ 's weighted performance on criterion  $C_j$  to the fuzzy maximum. This setting is in line with the optimal decision of Zadeh (1973) who states that “in a fuzzy environment, objective and constraints formally have the same nature and their confluence can be represented by the intersection of fuzzy sets”.

$$u_{R_j}(i) = \sup \left( z_{ij}^\lambda \cap M_{\max}^j \right) \quad (7.11)$$

Similarly, the degree to which alternative  $A_i$  is not the worst alternative with respect to criterion  $C_j$  can be calculated by comparing the weighted fuzzy performance ( $w_{jx_{ij}}$ ) of alternative  $A_i$  with the fuzzy minimum ( $M_{\min}^j$ ), as

$$u_{L_j}(i) = 1 - \sup \left( z_{ij}^\lambda \cap M_{\min}^j \right) \quad (7.12)$$

The degree of optimality (or preferability) of alternative  $A_i$  over all other alternatives with respect to criterion  $C_j$  is thus determined by

$$r_{ij}^\lambda = \frac{u_{R_j}(i) + u_{L_j}(i)}{2} \quad (7.13)$$

A fuzzy singleton matrix (Zadeh, 1973) can be obtained from the weighted fuzzy performance matrix based on (7.7)-(7.13), given as

$$R^\lambda = \begin{bmatrix} r_{11}^\lambda & r_{12}^\lambda & \dots & r_{1m}^\lambda \\ r_{21}^\lambda & r_{22}^\lambda & \dots & r_{2m}^\lambda \\ \dots & \dots & \dots & \dots \\ r_{n1}^\lambda & r_{n2}^\lambda & \dots & r_{nm}^\lambda \end{bmatrix} \quad (7.14)$$

To determine the overall performance of each alternative across all criteria, the concept based on the ideal solution is proposed. This concept has since been widely used in developing various methodologies for solving different practical decision problems (Wibowo and Deng, 2009). This is due to (a) its simplicity and comprehensibility in concept, (b) its computation efficiency, and (c) its ability to measure the relative performance of the decision alternatives in a simple mathematical form.

Based on the concept of the ideal solution above, the positive ideal solution  $A^{\lambda+}$  and the negative ideal solution  $A^{\lambda-}$  can be determined respectively from (7.14), shown as in (7.15) and (7.16).

$$\begin{aligned} A^{\lambda+} &= (a_1^{\lambda+}, a_2^{\lambda+}, \dots, a_m^{\lambda+}) \\ A^{\lambda-} &= (a_1^{\lambda-}, a_2^{\lambda-}, \dots, a_m^{\lambda-}) \end{aligned} \quad (7.15)$$

where

$$\begin{aligned} a_j^{\lambda+} &= \sup (r_{1j}^{\lambda}, r_{2j}^{\lambda}, \dots, r_{nj}^{\lambda}) \\ a_j^{\lambda-} &= \inf (r_{1j}^{\lambda}, r_{2j}^{\lambda}, \dots, r_{nj}^{\lambda}) \end{aligned} \quad (7.16)$$

Based on (7.15)-(7.16), the Hamming distance between each alternative and the positive ideal solution  $S_i^{\lambda+}$  and between the alternative and the negative ideal solution  $S_i^{\lambda-}$  can be respectively calculated as

$$S_i^{\lambda+} = \sum_{j=1}^m (a_j^{\lambda+} - r_{ij}^{\lambda}), \quad (7.17)$$

$$S_i^{\lambda-} = \sum_{j=1}^m (r_{ij}^{\lambda} - a_j^{\lambda-}), \quad (7.18)$$

A preferred alternative should have a higher degree of similarity to the positive ideal solution, and a lower degree of similarity to the negative ideal solution (Hwang and Yoon, 1981; Shipley et al., 1991). Based on this perception, an overall performance index for each alternative with the decision makers'  $\lambda$  degree of optimism towards risk can be calculated in a simple manner.

$$P_i^\lambda = \frac{S_i^{\lambda-}}{S_i^{\lambda+} + S_i^{\lambda-}}, \quad i=1, 2, \dots, n. \quad (7.19)$$

The larger the performance index value, the more preferred the alternative  $A_i$ .

The algorithm presented above can be summarized as follows:

- Step 1. Obtain the fuzzy decision matrix for each decision maker, as expressed in (7.1).
- Step 2. Obtain the weighting vector of each decision maker for the criteria, as expressed in (7.2).
- Step 3. Obtain the weighted fuzzy performance matrix by multiplying the fuzzy decision matrix (7.1) and the fuzzy weighting vector (7.2) for each decision maker given as in (7.3).
- Step 4. Introduce the concept based on  $\lambda$  ( $0 \leq \lambda \leq 1$ ) for reflecting the decision maker's attitude towards risk defined as in (7.4).
- Step 5. Obtain the fuzzy performance matrix for individual decision makers given as in (7.3).
- Step 6. Obtain the overall fuzzy group performance matrix (7.6) by averaging the fuzzy assessments made by individual decision makers as given in (7.5).

- Step 7. Determine the fuzzy maximum which represents the best fuzzy performance ratings among all the alternatives as the positive fuzzy ideal solution by (7.7), (7.9), and (7.11).
- Step 8. Determine the fuzzy minimum which represents the worst fuzzy performance ratings among all the alternatives as the negative fuzzy ideal solution by (7.8), (7.10), and (7.12).
- Step 9. Determine the degree of optimality (or preferability) of alternative  $A_i$  over all other alternatives with respect to criterion  $C_j$  by (7.13).
- Step 10. Obtain the fuzzy singleton matrix based on (7.7)-(7.13), given as (7.14).
- Step 11. Determine the positive ideal solution and the negative ideal solution from (7.14), shown as in (7.15) and (7.16) respectively.
- Step 12. Calculate the Hamming distance between each alternative and the positive ideal solution and between the alternative and the negative ideal solution by (7.17) and (7.18) respectively.
- Step 13. Compute the overall performance index for each alternative by (7.19).
- Step 14. Rank the alternatives in descending order of their performance indexes.

### 7.3 Concluding Remarks

The process of evaluating and selecting the best alternative in multicriteria group decision making has become a difficult challenge for decision makers due to the risk inherent in the fuzzy multicriteria group decision making problem. To deal with this problem, this chapter presents a risk-oriented approach for adequately modelling the inherent risk in the multicriteria group decision making process. Linguistic variables approximated by triangular

fuzzy numbers are used for representing the uncertain and imprecise assessments of the decision makers in evaluating the relative importance of the evaluation criteria and the performance of alternatives. The concept based on the ideal solution is introduced for determining the overall performance of each alternative across all criteria.

The proposed approach developed in this chapter has several advantages including (a) its ability to deal with the multicriteria group decision making problem involving multiple decision makers, (b) its ability to adequately handle the subjectiveness and imprecision of the decision making process, and (c) its capability of incorporating the risk inherent in the group decision making process.

## **Chapter 8**

# **Hospital Location Evaluation and Selection under Uncertainty**

### **8.1 Introduction**

People have been becoming more health conscious with their increasing focus on the quality of their health care (Wu et al., 2007). As a result, there is an increasing high demand on quality medical services. To effectively meet this demand, hospital owners are developing strategies and policies for improving the provision of medical services through the establishment of new hospitals (Brown and Barnett, 2004). By doing so, these hospitals can achieve competitive advantages that are vital to their future growth.

In establishing new hospitals, the location and proximity of the hospital to the potential patients are the important factors for these hospitals to remain competitive and survive. This is because the largest segment of a hospital's market share comes from an area of proximity to the hospital (Goldstein et al., 2002; Brown and Barnett, 2004). Recent surveys have shown that most hospitals located in rural areas have struggled in recent years because of the travel distance to the hospital and the lack of transportation in those rural areas (Chu and Chu, 2000; Goldstein et al., 2002; Wu et al., 2007). As a result, evaluating and selecting the most suitable hospital location for establishing a new hospital is of priority concern for hospital owners to achieve a competitive advantage.



The process of evaluating and selecting hospital location alternatives, however, is complex. The complexity of the selection process is due to the multi-dimensional nature of the decision making process, the conflicting nature of the multiple selection criteria (Brown and Barnett, 2004), and the presence of subjectiveness and imprecision in the decision making process (Wu et al., 2007). It is common for the decision maker to use subjective assessments with respect to the criteria importance and the hospital location's performance with respect to each criterion. To ensure that the hospital location evaluation and selection process is carried out in a consistent manner, a comprehensive evaluation of the hospital location's overall performance is required.

This purpose of this chapter is to formulate the hospital location evaluation and selection problem as a multicriteria analysis problem for facilitating the use of the pairwise comparison based approach developed in Chapter 4 in solving the problem. By doing so, the chapter aims to demonstrate the applicability of the pairwise comparison based approach developed for adequately modelling the inherent subjectiveness and imprecision in the decision making process and reducing the cognitively demanding nature of the evaluation and selection process on the decision maker.

## **8.2 The Hospital Location Evaluation and Selection**

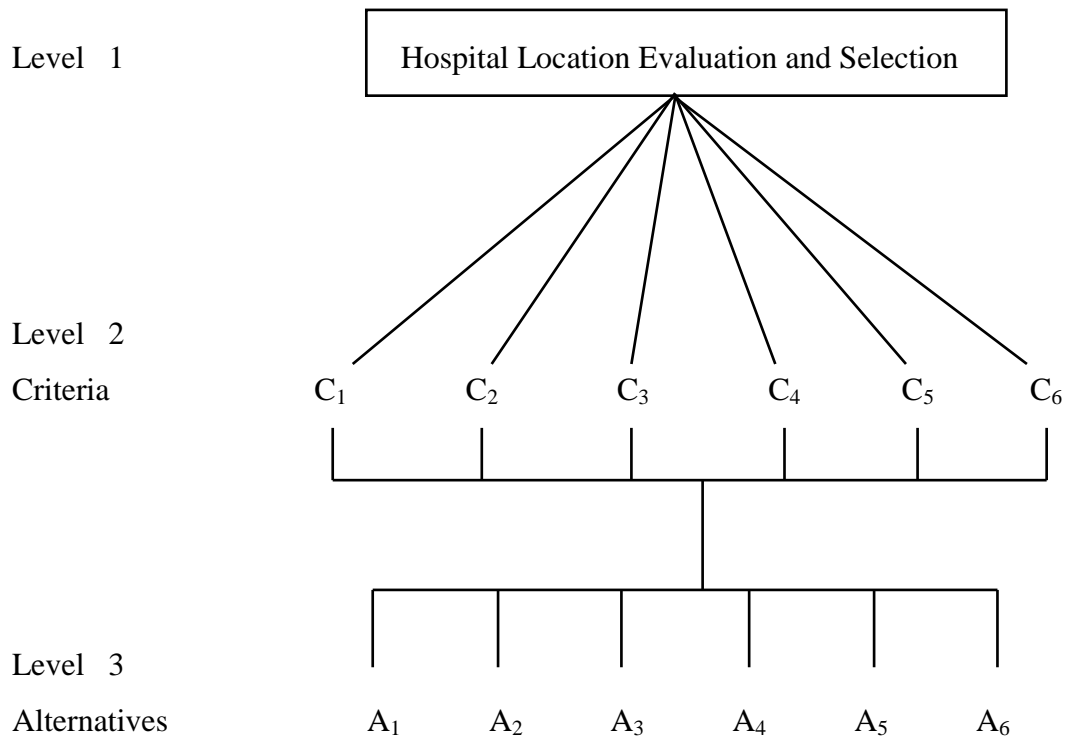
According to the Taiwan Department of Health, while 18,777 hospitals were operating in 2003, that figure was increased to 19,240 in 2004, representing an annual increase of more than 2.47% (Wu et al., 2007). Additionally, a survey conducted by the World Health Organization in 1993 found that the global aging phenomenon is no exception in Taiwan,

with the island officially becoming a rapidly aging society (Lin and Wu, 2007). These figures show that Taiwan has enormous potential for the establishment of new hospitals due to the increasing demand in the medical care sector.

Against this background, a well-known hospital operator in Taiwan decides to take this opportunity to build a new hospital for meeting the future demand in the medical care sector. In order for the new hospital to achieve competitive advantages over its competitors, selecting the most suitable location for the new hospital development is a critical aspect (Lin and Wu, 2007).

The hospital location selection starts with the formation of a committee consisting of several hospital administrators and academics. A Delphi approach is used to determine the evaluation and selection criteria which would be appropriate for the evaluation and selection process. Based on their thorough discussion, six selection criteria are identified for evaluating ten hospital location alternatives. These selection criteria include Financial Attractiveness ( $C_1$ ), Demand Potential ( $C_2$ ), Organizational Strategy ( $C_3$ ), Supporting Industries ( $C_4$ ), Government Influence ( $C_5$ ), and Marketing Dynamics ( $C_6$ ). The hierarchical structure of hospital location evaluation and selection problem is shown in Figure 8.1.

The Financial Attractiveness ( $C_1$ ) concerns with the subjective assessment of the decision maker on the economical feasibility of the hospital's investment with respect to its business strategy. Factors such as the capital required for building the hospital, the labour cost of hospital personnel in the region, and the contribution of the hospital to organizational profitability usually are taken into consideration (Raju and Lonial, 2002; Shen, 2003).



Legend:

$C_1$ : Financial Attractiveness

$C_2$ : Demand Potential

$C_3$ : Organizational Strategy

$C_4$ : Supporting Industries

$C_5$ : Government Influence

$C_6$ : Marketing Dynamics

$A_i$  ( $i = 1, 2, \dots, n$ ): Hospital Locations.

**Figure 8.1 The Hierarchical Structure of the Hospital Location Evaluation and Selection Problem**

Demand Potential ( $C_2$ ) refers to the subjective assessment of the decision maker in regards to the factors influencing the medical market demand. This is measured by the population number requiring medical services, the population density of the region, and the population age distribution in the region (Lin and Wu, 2007).

Organizational Strategy ( $C_3$ ) concerns with the subjective assessment of the decision maker on attitudes of the management towards its business practices and competitors. This is often determined by the management objective for achieving a long term success, the attitude of management towards competition from other hospitals, and the policymaker's attitudes towards management's style (Brekke et al., 2008).

Supporting Industries ( $C_4$ ) involves the subjective assessment of the decision maker on the upper echelons of the medical sector and their supporting sectors. This is usually assessed by the support from the health sector, the medicine practice and the pharmaceutical sector including biochemistry technology and cultivation of medical personnel, and the hospital administration sector which includes management consultants and the information technology industry (Lin and Wu, 2007).

Government Influence ( $C_5$ ) refers to the subjective assessment of the decision maker on the governmental policy towards establishing hospitals in order to strengthen their competitiveness. This is assessed by qualifications of the hospital's establishment, efforts to promote a medical network, and promulgating tasks that require a hospital's assessment (Wu and Lin, 2004; Brekke et al., 2008).

Marketing Dynamics ( $C_6$ ) involve the subjective assessment of the decision maker on circumstances that would negatively impact the medical care sector and possibly influence current market competition. This is measured by violent change in market demand that resulted in a decreased medical demand, dramatic fluctuations in production costs, and significant changes in the financial market and exchange rate that incur changes in the cost of medical instrumentation and pharmaceuticals (Wu and Lin, 2004).

Based on the discussion above, it can be seen that the hospital location evaluation and selection problem is complicated due to (a) the multi-dimensional nature of the decision making process, (b) the conflicting nature of the multiple selection criteria, and (c) the presence of subjectiveness and imprecision in the decision making process.

It is therefore necessary to apply the pairwise comparison based approach developed in Chapter 4 for solving the hospital location evaluation and selection problem. The pairwise comparison based approach is capable of adequately handling the subjectiveness and imprecision of the human decision making process and greatly reducing the cognitive demanding on the decision maker in the evaluation process. As a result, effective decisions can be made based on the proper consideration of all these issues.

### **8.3 Data Collection**

A comprehensive investigation has been carried out to collect the required data for the evaluation process. Subjective assessments are usually given by the decision maker in evaluating the performance of hospital location alternatives and the importance of the selection criteria. To facilitate the subjective evaluation process, linguistic variables are used for representing the subjective assessments of the decision maker. To ensure the efficiency of the computation process for making the selection decision, fuzzy numbers are used to approximate the linguistic variables in the evaluation process.

It is observed that two common issues are involved in this hospital location evaluation and selection process. The evaluation criteria are generally multi-dimensional in nature and a

simultaneous consideration of those multiple criteria is required for making effective selection decisions. The evaluation process involves subjective assessments, resulting in qualitative and vague data being used.

Using the pairwise comparison technique based on the linguistic variables defined as in Table 4.1, the fuzzy reciprocal judgment matrices for the performance of hospital location alternatives in regard to each criterion can be determined. Tables 8.1 to 8.6 show the results for the Financial attractiveness criterion ( $C_1$ ), Demand potential criterion ( $C_2$ ), Organizational strategy criterion ( $C_3$ ), Supporting industries criterion ( $C_4$ ), Government influence criterion ( $C_5$ ), and Marketing dynamics criterion ( $C_6$ ) respectively.

**Table 8.1 A Fuzzy Reciprocal Judgment Matrix for the Financial Attractiveness Criterion**

$$C_1 = \begin{matrix} & \begin{matrix} A_1 & A_2 & A_3 & A_4 & A_5 & A_6 & A_7 & A_8 & A_9 & A_{10} \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \\ A_7 \\ A_8 \\ A_9 \\ A_{10} \end{matrix} & \begin{bmatrix} \tilde{1} & \tilde{3} & \tilde{7} & \tilde{5}^{-1} & \tilde{5}^{-1} & \tilde{3}^{-1} & \tilde{3} & \tilde{9}^{-1} & \tilde{9}^{-1} & \tilde{5} \\ \tilde{3}^{-1} & \tilde{1} & \tilde{9} & \tilde{3}^{-1} & \tilde{9}^{-1} & \tilde{7}^{-1} & \tilde{7} & \tilde{7} & \tilde{9} & \tilde{9} \\ \tilde{7}^{-1} & \tilde{9}^{-1} & \tilde{1} & \tilde{3} & \tilde{7} & \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{7}^{-1} & \tilde{7} & \tilde{7} \\ \tilde{5} & \tilde{3} & \tilde{3}^{-1} & \tilde{1} & \tilde{3} & \tilde{3} & \tilde{3} & \tilde{3}^{-1} & \tilde{3} & \tilde{7}^{-1} \\ \tilde{5} & \tilde{9} & \tilde{7}^{-1} & \tilde{3}^{-1} & \tilde{1} & \tilde{5}^{-1} & \tilde{5}^{-1} & \tilde{3}^{-1} & \tilde{3} & \tilde{3}^{-1} \\ \tilde{3} & \tilde{7} & \tilde{3} & \tilde{3}^{-1} & \tilde{5} & \tilde{1} & \tilde{9} & \tilde{5} & \tilde{5} & \tilde{5}^{-1} \\ \tilde{3}^{-1} & \tilde{7}^{-1} & \tilde{3} & \tilde{3}^{-1} & \tilde{5} & \tilde{9}^{-1} & \tilde{1} & \tilde{5}^{-1} & \tilde{9}^{-1} & \tilde{5} \\ \tilde{9} & \tilde{7}^{-1} & \tilde{7} & \tilde{3} & \tilde{3} & \tilde{5}^{-1} & \tilde{5} & \tilde{1} & \tilde{9}^{-1} & \tilde{5} \\ \tilde{9} & \tilde{9}^{-1} & \tilde{7}^{-1} & \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{5}^{-1} & \tilde{9} & \tilde{9} & \tilde{1} & \tilde{7}^{-1} \\ \tilde{5}^{-1} & \tilde{9}^{-1} & \tilde{7}^{-1} & \tilde{7} & \tilde{3} & \tilde{5} & \tilde{5}^{-1} & \tilde{5}^{-1} & \tilde{7} & \tilde{1} \end{bmatrix} \end{matrix}$$

**Table 8.2 A Fuzzy Reciprocal Judgment Matrix for the Demand Potential Criterion**

	$A_1$	$A_2$	$A_3$	$A_4$	$A_5$	$A_6$	$A_7$	$A_8$	$A_9$	$A_{10}$
$C_2 =$	$A_1$	$\tilde{1}$	$\tilde{5}$	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{7}^{-1}$	$\tilde{7}$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{9}$
	$A_2$	$\tilde{5}^{-1}$	$\tilde{1}$	$\tilde{9}$	$\tilde{3}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}$
	$A_3$	$\tilde{5}$	$\tilde{9}^{-1}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$
	$A_4$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{1}$	$\tilde{9}$	$\tilde{5}$	$\tilde{9}^{-1}$	$\tilde{7}^{-1}$	$\tilde{7}^{-1}$
	$A_5$	$\tilde{7}$	$\tilde{3}^{-1}$	$\tilde{9}$	$\tilde{9}^{-1}$	$\tilde{1}$	$\tilde{3}$	$\tilde{7}$	$\tilde{5}^{-1}$	$\tilde{9}^{-1}$
	$A_6$	$\tilde{7}^{-1}$	$\tilde{5}$	$\tilde{9}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{7}$	$\tilde{5}^{-1}$	$\tilde{3}$
	$A_7$	$\tilde{3}$	$\tilde{3}$	$\tilde{5}$	$\tilde{9}$	$\tilde{7}^{-1}$	$\tilde{7}^{-1}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{5}$
	$A_8$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{3}$	$\tilde{7}$	$\tilde{5}$	$\tilde{3}$	$\tilde{1}$	$\tilde{7}^{-1}$	$\tilde{7}$
	$A_9$	$\tilde{3}^{-1}$	$\tilde{9}$	$\tilde{3}$	$\tilde{7}$	$\tilde{9}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{7}$	$\tilde{1}$
	$A_{10}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{7}$	$\tilde{7}^{-1}$	$\tilde{9}^{-1}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$

**Table 8.3 A Fuzzy Reciprocal Judgment Matrix for the Organizational Strategy**

**Criterion**

	$A_1$	$A_2$	$A_3$	$A_4$	$A_5$	$A_6$	$A_7$	$A_8$	$A_9$	$A_{10}$
$C_3 =$	$A_1$	$\tilde{1}$	$\tilde{9}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{7}$	$\tilde{3}$	$\tilde{9}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$
	$A_2$	$\tilde{9}^{-1}$	$\tilde{1}$	$\tilde{9}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{7}^{-1}$	$\tilde{7}$	$\tilde{7}^{-1}$	$\tilde{9}$
	$A_3$	$\tilde{3}$	$\tilde{9}^{-1}$	$\tilde{1}$	$\tilde{3}$	$\tilde{9}$	$\tilde{9}^{-1}$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$	$\tilde{7}$
	$A_4$	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{9}$	$\tilde{9}^{-1}$
	$A_5$	$\tilde{7}^{-1}$	$\tilde{5}$	$\tilde{9}^{-1}$	$\tilde{3}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{5}$	$\tilde{3}^{-1}$
	$A_6$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{9}$	$\tilde{5}$	$\tilde{3}$	$\tilde{1}$	$\tilde{5}$	$\tilde{3}$	$\tilde{5}^{-1}$
	$A_7$	$\tilde{9}$	$\tilde{7}$	$\tilde{9}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}$	$\tilde{9}$	$\tilde{3}^{-1}$
	$A_8$	$\tilde{9}$	$\tilde{7}^{-1}$	$\tilde{3}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}$	$\tilde{9}$
	$A_9$	$\tilde{5}$	$\tilde{7}$	$\tilde{3}$	$\tilde{9}$	$\tilde{3}$	$\tilde{5}$	$\tilde{9}^{-1}$	$\tilde{5}$	$\tilde{1}$
	$A_{10}$	$\tilde{5}$	$\tilde{9}^{-1}$	$\tilde{7}^{-1}$	$\tilde{7}^{-1}$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}$

**Table 8.4 A Fuzzy Reciprocal Judgment Matrix for the Supporting Industries**

**Criterion**

	$A_1$	$A_2$	$A_3$	$A_4$	$A_5$	$A_6$	$A_7$	$A_8$	$A_9$	$A_{10}$	
$C_4 =$	$A_1$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}$	$\tilde{7}^{-1}$	$\tilde{3}$	$\tilde{5}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$
	$A_2$	$\tilde{3}$	$\tilde{1}$	$\tilde{9}^{-1}$	$\tilde{3}$	$\tilde{5}$	$\tilde{7}^{-1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{9}$
	$A_3$	$\tilde{7}$	$\tilde{9}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}$	$\tilde{5}$	$\tilde{7}^{-1}$
	$A_4$	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{1}$	$\tilde{7}$	$\tilde{9}$	$\tilde{9}^{-1}$	$\tilde{7}$	$\tilde{7}$	$\tilde{7}^{-1}$
	$A_5$	$\tilde{7}$	$\tilde{5}^{-1}$	$\tilde{9}$	$\tilde{7}^{-1}$	$\tilde{1}$	$\tilde{7}$	$\tilde{5}$	$\tilde{7}$	$\tilde{3}$	$\tilde{5}$
	$A_6$	$\tilde{3}^{-1}$	$\tilde{7}$	$\tilde{5}$	$\tilde{9}^{-1}$	$\tilde{7}^{-1}$	$\tilde{1}$	$\tilde{5}$	$\tilde{5}^{-1}$	$\tilde{5}^{-1}$	$\tilde{7}$
	$A_7$	$\tilde{5}$	$\tilde{3}^{-1}$	$\tilde{9}$	$\tilde{9}$	$\tilde{5}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}$	$\tilde{9}^{-1}$	$\tilde{3}$	$\tilde{5}^{-1}$
	$A_8$	$\tilde{9}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{7}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}$	$\tilde{9}$	$\tilde{1}$	$\tilde{3}$	$\tilde{5}$
	$A_9$	$\tilde{5}$	$\tilde{3}$	$\tilde{5}^{-1}$	$\tilde{7}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{9}^{-1}$
	$A_{10}$	$\tilde{3}$	$\tilde{9}^{-1}$	$\tilde{7}$	$\tilde{7}$	$\tilde{5}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}$	$\tilde{5}^{-1}$	$\tilde{9}$	$\tilde{1}$

**Table 8.5 A Fuzzy Reciprocal Judgment Matrix for the Government Influence**

**Criterion**

	$A_1$	$A_2$	$A_3$	$A_4$	$A_5$	$A_6$	$A_7$	$A_8$	$A_9$	$A_{10}$	
$C_5 =$	$A_1$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{7}^{-1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{9}^{-1}$	$\tilde{9}^{-1}$
	$A_2$	$\tilde{3}$	$\tilde{1}$	$\tilde{9}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}$
	$A_3$	$\tilde{5}^{-1}$	$\tilde{9}$	$\tilde{1}$	$\tilde{5}$	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{9}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}$
	$A_4$	$\tilde{3}$	$\tilde{3}$	$\tilde{5}^{-1}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{9}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{9}$
	$A_5$	$\tilde{5}$	$\tilde{5}$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{1}$	$\tilde{5}^{-1}$	$\tilde{5}^{-1}$	$\tilde{9}$	$\tilde{9}$	$\tilde{9}$
	$A_6$	$\tilde{7}$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{5}$	$\tilde{5}^{-1}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{5}$	$\tilde{3}$
	$A_7$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$	$\tilde{9}^{-1}$	$\tilde{9}$	$\tilde{5}$	$\tilde{3}$	$\tilde{1}$	$\tilde{3}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$
	$A_8$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{3}$	$\tilde{3}$	$\tilde{5}$	$\tilde{3}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{3}^{-1}$	$\tilde{9}$
	$A_9$	$\tilde{9}$	$\tilde{3}$	$\tilde{5}$	$\tilde{5}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{9}$	$\tilde{3}$	$\tilde{1}$	$\tilde{3}^{-1}$
	$A_{10}$	$\tilde{9}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{9}^{-1}$	$\tilde{9}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{9}^{-1}$	$\tilde{3}$	$\tilde{1}$



**Table 8.6 A Fuzzy Reciprocal Judgment Matrix for the Marketing Dynamics**  
**Criterion**

	$A_1$	$A_2$	$A_3$	$A_4$	$A_5$	$A_6$	$A_7$	$A_8$	$A_9$	$A_{10}$	
$C_6 =$	$A_1$	$\tilde{1}$	$\tilde{5}^{-1}$	$\tilde{5}$	$\tilde{3}$	$\tilde{7}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$	$\tilde{9}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$
	$A_2$	$\tilde{5}$	$\tilde{1}$	$\tilde{9}^{-1}$	$\tilde{3}^{-1}$	$\tilde{9}$	$\tilde{9}^{-1}$	$\tilde{9}^{-1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{3}^{-1}$
	$A_3$	$\tilde{5}^{-1}$	$\tilde{9}$	$\tilde{1}$	$\tilde{5}^{-1}$	$\tilde{7}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{7}$	$\tilde{7}$	$\tilde{7}$
	$A_4$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{5}$	$\tilde{1}$	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}$
	$A_5$	$\tilde{7}$	$\tilde{9}^{-1}$	$\tilde{7}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{5}^{-1}$	$\tilde{7}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}$
	$A_6$	$\tilde{7}$	$\tilde{9}$	$\tilde{3}$	$\tilde{3}$	$\tilde{5}$	$\tilde{1}$	$\tilde{9}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{3}$
	$A_7$	$\tilde{5}$	$\tilde{9}$	$\tilde{7}$	$\tilde{7}$	$\tilde{7}^{-1}$	$\tilde{9}^{-1}$	$\tilde{1}$	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$	$\tilde{5}^{-1}$
	$A_8$	$\tilde{9}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}$	$\tilde{5}$	$\tilde{3}$	$\tilde{7}$	$\tilde{1}$	$\tilde{9}^{-1}$	$\tilde{3}$
	$A_9$	$\tilde{9}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{5}^{-1}$	$\tilde{5}$	$\tilde{9}$	$\tilde{1}$	$\tilde{7}$
	$A_{10}$	$\tilde{5}$	$\tilde{3}$	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{1}$

In order to determine the relative importance of the selection criteria, pairwise comparison is used based on the linguistic variables defined as in Table 4.1, resulting in the determination of a fuzzy judgment matrix as shown in Table 8.7. Given the problem structure and the available data as above, the overall objective of the hospital location selection problem is to produce an overall performance index for each hospital location alternative by effectively aggregating the obtained assessments for criteria weights and performance ratings.

**Table 8.7 A Fuzzy Reciprocal Judgment Matrix for the Relative Importance of the Selection Criteria**

$$W = \begin{array}{c} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \end{array} \begin{bmatrix} \tilde{1} & \tilde{7} & \tilde{9} & \tilde{5} & \tilde{7}^{-1} & \tilde{3} \\ \tilde{7}^{-1} & \tilde{1} & \tilde{9} & \tilde{3} & \tilde{5} & \tilde{5}^{-1} \\ \tilde{9}^{-1} & \tilde{9}^{-1} & \tilde{1} & \tilde{3}^{-1} & \tilde{3} & \tilde{9}^{-1} \\ \tilde{5}^{-1} & \tilde{3}^{-1} & \tilde{3} & \tilde{1} & \tilde{5}^{-1} & \tilde{5}^{-1} \\ \tilde{7} & \tilde{5}^{-1} & \tilde{3}^{-1} & \tilde{5} & \tilde{1} & \tilde{3}^{-1} \\ \tilde{3}^{-1} & \tilde{5} & \tilde{9} & \tilde{5} & \tilde{3} & \tilde{1} \end{bmatrix}$$

## 8.4 Results and Discussion

The discussion above shows that (a) the size of the problem is large, (b) subjective assessments are usually provided by the decision maker in assessing the performances of hospital location alternatives with respect to each criterion, (c) the decision maker's assessments on criteria weights and performance ratings are represented by linguistic terms approximated by triangular fuzzy numbers, and (d) simultaneous consideration of those multiple criteria is required for making effective selection decisions. To deal with this kind of hospital location evaluation and selection problem situation, the pairwise comparison based approach developed in Chapter 4 is appropriate for effectively handling this problem.

The hospital location selection process starts with the determination of the decision matrix for the hospital location selection problem using (4.3) and (4.4). The results can be obtained as in Table 8.8. Similarly, using the fuzzy extent analysis described in (4.3) and (4.4), the fuzzy criteria weights can be calculated as

$$\begin{array}{lll} w_1 = (0.17, 0.28, 0.62) & w_2 = (0.14, 0.20, 0.48) & w_3 = (0.02, 0.05, 0.23) \\ w_4 = (0.06, 0.18, 0.33) & w_5 = (0.09, 0.15, 0.32) & w_6 = (0.16, 0.26, 0.47) \end{array}$$

Using the fuzzy arithmetic operations based on (4.7), the weighted fuzzy performance matrix for the hospital location selection problem can be determined as in Table 8.9.

**Table 8.8 The Decision Matrix for the Hospital Location Selection Problem**

$$X = \begin{bmatrix} (0.03, 0.08, 0.22) & (0.07, 0.12, 0.37) & (0.02, 0.10, 0.19) & (0.02, 0.04, 0.13) & (0.02, 0.05, 0.11) & (0.02, 0.10, 0.19) \\ (0.11, 0.18, 0.43) & (0.03, 0.08, 0.19) & (0.05, 0.10, 0.24) & (0.05, 0.10, 0.25) & (0.05, 0.07, 0.19) & (0.05, 0.10, 0.24) \\ (0.04, 0.11, 0.26) & (0.15, 0.29, 0.39) & (0.04, 0.12, 0.31) & (0.08, 0.11, 0.29) & (0.06, 0.13, 0.26) & (0.04, 0.12, 0.31) \\ (0.03, 0.09, 0.21) & (0.04, 0.07, 0.26) & (0.06, 0.09, 0.37) & (0.06, 0.13, 0.32) & (0.03, 0.11, 0.24) & (0.06, 0.09, 0.37) \\ (0.02, 0.08, 0.27) & (0.03, 0.13, 0.22) & (0.03, 0.08, 0.26) & (0.07, 0.16, 0.34) & (0.04, 0.13, 0.31) & (0.03, 0.08, 0.26) \\ (0.04, 0.16, 0.34) & (0.05, 0.13, 0.26) & (0.08, 0.11, 0.28) & (0.03, 0.09, 0.26) & (0.07, 0.11, 0.34) & (0.08, 0.11, 0.28) \\ (0.03, 0.06, 0.21) & (0.04, 0.11, 0.22) & (0.07, 0.12, 0.35) & (0.04, 0.10, 0.33) & (0.06, 0.09, 0.22) & (0.07, 0.12, 0.35) \\ (0.05, 0.14, 0.32) & (0.03, 0.13, 0.27) & (0.03, 0.09, 0.34) & (0.05, 0.12, 0.29) & (0.05, 0.11, 0.36) & (0.03, 0.09, 0.34) \\ (0.04, 0.12, 0.29) & (0.06, 0.15, 0.31) & (0.04, 0.16, 0.36) & (0.02, 0.05, 0.18) & (0.03, 0.12, 0.39) & (0.04, 0.16, 0.36) \\ (0.02, 0.10, 0.38) & (0.02, 0.05, 0.16) & (0.02, 0.05, 0.18) & (0.04, 0.12, 0.26) & (0.04, 0.08, 0.28) & (0.02, 0.05, 0.18) \end{bmatrix}$$

**Table 8.9 The Weighted Fuzzy Performance Matrix for the Hospital Location Selection Problem**

$$Z = \begin{bmatrix} (0.005, 0.022, 0.136) & (0.010, 0.024, 0.178) & (0.001, 0.05, 0.044) & (0.001, 0.007, 0.043) & (0.002, 0.008, 0.035) & (0.003, 0.026, 0.089) \\ (0.019, 0.050, 0.267) & (0.004, 0.016, 0.091) & (0.001, 0.005, 0.055) & (0.003, 0.018, 0.083) & (0.005, 0.011, 0.061) & (0.008, 0.026, 0.113) \\ (0.007, 0.031, 0.161) & (0.021, 0.058, 0.187) & (0.001, 0.006, 0.071) & (0.080, 0.110, 0.290) & (0.006, 0.020, 0.083) & (0.006, 0.031, 0.146) \\ (0.005, 0.025, 0.130) & (0.006, 0.014, 0.125) & (0.001, 0.005, 0.085) & (0.004, 0.023, 0.106) & (0.003, 0.017, 0.077) & (0.010, 0.023, 0.174) \\ (0.003, 0.022, 0.167) & (0.004, 0.026, 0.106) & (0.001, 0.004, 0.060) & (0.004, 0.029, 0.112) & (0.004, 0.020, 0.099) & (0.005, 0.021, 0.122) \\ (0.007, 0.045, 0.211) & (0.007, 0.026, 0.125) & (0.002, 0.006, 0.064) & (0.002, 0.016, 0.086) & (0.016, 0.024, 0.139) & (0.013, 0.029, 0.132) \\ (0.005, 0.017, 0.130) & (0.006, 0.022, 0.106) & (0.001, 0.006, 0.081) & (0.002, 0.018, 0.109) & (0.06, 0.017, 0.109) & (0.011, 0.031, 0.165) \\ (0.009, 0.039, 0.198) & (0.004, 0.026, 0.130) & (0.001, 0.005, 0.078) & (0.003, 0.022, 0.096) & (0.006, 0.014, 0.071) & (0.005, 0.023, 0.160) \\ (0.007, 0.034, 0.180) & (0.008, 0.031, 0.149) & (0.001, 0.002, 0.083) & (0.001, 0.009, 0.059) & (0.005, 0.017, 0.115) & (0.006, 0.042, 0.169) \\ (0.003, 0.028, 0.236) & (0.003, 0.011, 0.077) & (0.001, 0.003, 0.041) & (0.002, 0.022, 0.86) & (0.003, 0.018, 0.125) & (0.003, 0.013, 0.085) \end{bmatrix}$$

Following the approach illustrated in (4.8) to (4.20), an overall performance index for each hospital location alternative across all criteria can be calculated in a simple and efficient manner. Table 8.10 shows the overall performance index of all alternatives and their corresponding rankings. Alternative  $A_6$  is the preferred choice since it has the highest index of 0.78.

**Table 8.10 The Overall Performance Index and Ranking of Hospital Location Alternatives**

Hospital Location Alternative	Index	Ranking
$A_1$	0.64	5
$A_2$	0.70	3
$A_3$	0.58	8
$A_4$	0.62	6
$A_5$	0.57	9
$A_6$	0.78	1
$A_7$	0.54	10
$A_8$	0.72	2
$A_9$	0.69	4
$A_{10}$	0.59	7

The study suggests that the pairwise comparison based approach developed in Chapter 4 is capable for (a) dealing with the presence of subjectiveness and imprecision in hospital location evaluation and selection problem, (b) effectively handling the multi-dimensional nature of the selection process, and (c) reducing the cognitively demanding nature of the evaluation and selection process on the decision maker.

## **8.5 Concluding Remarks**

The hospital location evaluation and selection process is challenging due to the multi-dimensional nature of the process and the presence of subjectiveness and imprecision inherent in the human decision making process. As a result, how to handle the multi-dimensional nature of the selection process and adequately model the subjectiveness and imprecision becomes a critical issue for effectively solving the hospital location evaluation and selection problem in a real world setting.

To effectively solve this problem, this chapter has formulated the hospital location evaluation and selection problem as a multicriteria analysis problem and applied the pairwise comparison based approach developed in Chapter 4 to address the hospital location evaluation and selection problem. The result of this study shows that the pairwise comparison based approach applied to solve the hospital location evaluation and selection problem is capable of dealing with the presence of subjectiveness and imprecision in the hospital location evaluation and selection problem and adequately handling the cognitive demanding on the decision maker in the hospital location evaluation and selection process.

## **Chapter 9**

# **A Decision Support System Approach for Selecting International Distribution Centres under Uncertainty**

### **9.1 Introduction**

With the globalization of markets and intensive competition in international trade, organizations must rapidly respond to these challenging marketplace requirements for achieving their competitiveness (Czinkota and Ronkainen, 2005; Cheng and Tsai, 2009). To respond to this situation, organizations of various kinds have been looking for strategies to help them maintain their competitive advantages. One of these strategies as a popular option for organizations to implement is the development of international distribution centres for satisfying the growing demands from their customers worldwide (Cheng and Tsai, 2009).

An international distribution centre is a place which integrates the operations of manufacturing with land, sea and air transportation, storage, port and customs operations in order to achieve the efficient distribution of specific commodities (Ou and Chou, 2009). The adoption of these centres offers numerous advantages to organizations including storage, inland transport service, customs clearance service, consolidation, packaging, labelling and assembly services (Cheng and Tsai, 2009). The development of international distribution

centres is critical for organizations in transportation and distribution of commodities for improving their business effectiveness due to its capabilities in reducing cycle time, lowering operational costs, and improving better customer service (Chen et al., 2005; Hwang, 2005). By adopting the appropriate international distribution centre, modern organizations can gain competitive advantages that are vital to the organization's future growth.

In order for organizations to achieve a competitive advantage through the adoption of international distribution centres, it is critical that the most suitable international distribution centre location is selected. This is because the selection of the most suitable international distribution centre location helps organizations in reducing their operating costs while improving their services (Chen et al., 2005). As a result, evaluating and selecting the most suitable international distribution centre location from many available international distribution centre locations become a critical decision to be made.

The decision to evaluate and select the most suitable international distribution centre in an organization is complicated due to (a) the participation of multiple decision makers, (b) the availability of numerous international distribution centre alternatives, (c) the presence of inherent subjectiveness and imprecision of the human decision making process, (d) the cognitively demanding nature of the evaluation and selection process on the decision makers, and (e) the pressure to consider all multiple evaluation criteria simultaneously in a timely manner (Deng and Wibowo, 2008; Wibowo and Deng, 2010b).

To evaluate and select the most suitable international distribution centre across all the evaluation and selection criteria in effective and efficient manner, it is desirable to have a structured approach capable of (a) effectively aggregating the weightings of the criteria and

the performance ratings of individual international distribution centres for determining the overall suitability of each international distribution centre across all the selection criteria, and (b) appropriately providing an interactive mechanism that allows the decision makers to interact with the system for exploring the implications of various decision making behaviors on the selection decision being made. The application of such a decision support system (DSS) would greatly reduce the difficulty and the complexity faced by the decision makers in the process of solving the international distribution centre evaluation and selection problem.

The purpose of this chapter is to formulate the international distribution centre evaluation and selection problem as a multicriteria group decision making problem and to apply the DSS approach developed in Chapter 5 for solving the multicriteria group evaluation and selection problem in an efficient and effective manner. With the presentation of an empirical study of an international distribution centre evaluation and selection problem in a specific organization, this chapter aims to demonstrate the applicability of the proposed DSS approach in Chapter 5 for addressing the general international distribution centre evaluation and selection problem.

## **9.2 The International Distribution Centre Evaluation and Selection**

Argos is a market leader in multi-channel retail business. The company sells general merchandise products from over 700 stores throughout the UK and Europe (Baker, 2008). In recent years, the company has been experiencing a downturn in sales due to the intense global competition. In order for the company to remain competitive, it has to rapidly respond to



changing marketplace requirements by providing greater responsiveness to customers' demands whilst keeping costs at a low level (Wei et al., 2007). The decision is therefore taken to set up an international distribution centre for improving the effectiveness by collaborating different stages of a supply chain and coordinating the movement of products from many sources to various locations in the supply chain throughout the world (Ou and Chou, 2009).

A special committee is set up for evaluating and selecting the best location for an international distribution centre. It consists of three top managers from various functional departments within the organization including the general marketing manager ( $D_1$ ), the production manager ( $D_2$ ), and the business section manager ( $D_3$ ). The committee organizes a series of meetings to determine the selection criteria for evaluating and selecting the most suitable international distribution centre.

A consensus is reached based on a thorough investigation about the criteria for evaluating and selecting the international distribution centres. Six selection criteria are identified for evaluating and selecting nine international distribution centres including Service Orientation ( $C_1$ ), Convenience of Distribution ( $C_2$ ), Market Potential ( $C_3$ ), Cultural Perspective ( $C_4$ ), Government Policy ( $C_5$ ), and Infrastructure Capacity ( $C_6$ ) (Ou and Chou, 2009). The hierarchical structure of the international distribution centre evaluation and selection problem is shown in Figure 9.1.

Service Orientation ( $C_1$ ) involves the subjective assessment of the decision maker on the type of services that can be offered by the distribution centre. This includes value-added services: packaging, labelling, cargo processing and bar coding, storage services: bonded storage and

special cargo storage services; and support services: customs clearance, exhibition, insurance service and barcode recognition (Ou and Chou, 2009).

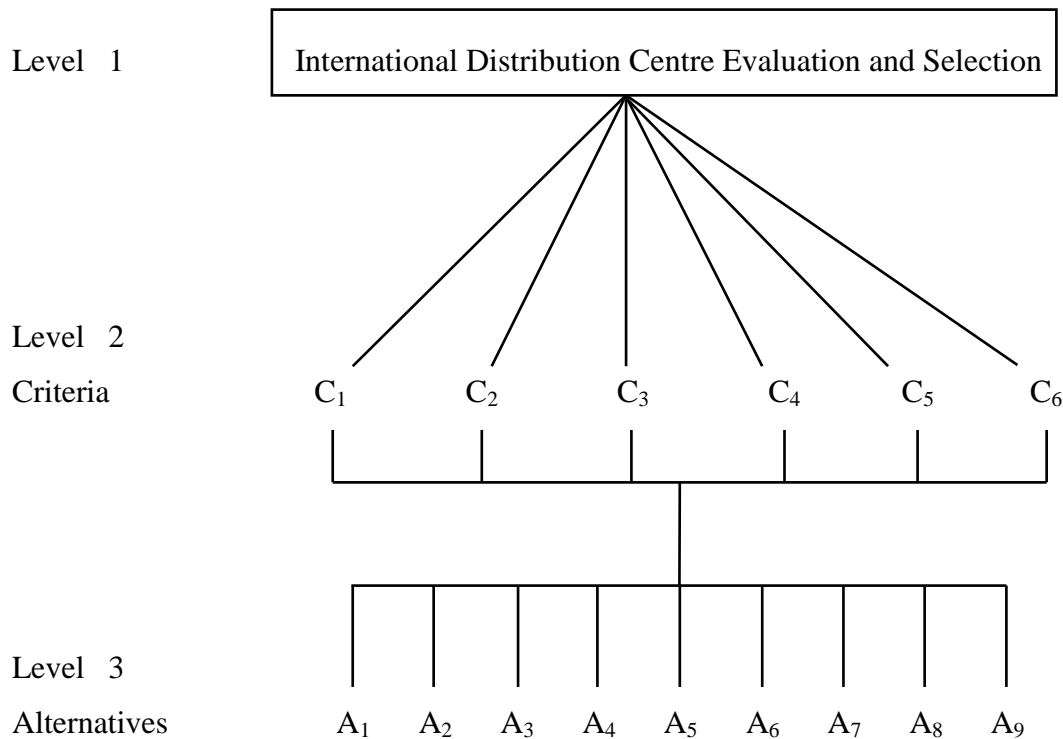
Convenience of Distribution ( $C_2$ ) concerns with the subjective assessment of the decision maker on the convenience of the international distribution centre's location. This is measured by the import distribution, the export distribution, the multinational distribution, the electronic transmission, and the inland transportation (Wei et al., 2007; Ou and Chou, 2009).

Market Potential ( $C_3$ ) refers to the subjective assessment of the decision maker on whether the on-site distribution centre is located in an area whereby consumers have the economic means to purchase imported products. The main areas of interest include product consumption trends in the export market, internal and external competition in the export market, and current market position as measured by broad economic performance standards.

Cultural Perspective ( $C_4$ ) focuses on the subjective assessment of the decision maker on the shared attitudes and practices adopted in the foreign country. This is measured by customs and social relationships, the degree of cultural unity, national integration and extent of ethnic and cultural differences in the foreign market, and cultural differences between the export market and the home market (Cheng and Tsai, 2009).

Government Policy ( $C_5$ ) involves with the subjective assessment of the decision maker on political factors concerning the foreign country. This includes the internal policy of the foreign government toward private organizations, and government regulations or restrictions that can affect organization's daily operations (Wei et al., 2007).

Infrastructure Capacity ( $C_6$ ) concerns with the subjective assessment of the decision maker on the existing and possible future infrastructure development and support provided by the local government. This is measured by physical distribution infrastructure, communications infrastructure, information technology infrastructure, and water and electricity supply infrastructure.



Legend:

$C_1$ : Service Orientation	$C_2$ : Convenience of Distribution
$C_3$ : Market Potential	$C_4$ : Cultural Perspective
$C_5$ : Government Policy	$C_6$ : Infrastructure Capacity

$A_i$  ( $i = 1, 2, \dots, n$ ): International Distribution Centres.

**Figure 9.1 The Hierarchical Structure for International Distribution Centre Evaluation and Selection**

Based on the discussion above, it can be seen that the international distribution centre evaluation and selection problem is complex and challenging. To make effective selection decisions, several decision makers are usually present, and multiple selection criteria have to be considered simultaneously. As a result, it is desirable to use a structured approach capable of comprehensively analyzing the overall performance of available international distribution centres in a specific decision setting.

### **9.3 Data Collection**

The international distribution centre evaluation and selection process begins with assessing the performance of each international distribution centre with respect to each criterion, and with assessing the importance of these criteria from multiple decision makers. The actual experience in evaluating and selecting the most suitable international distribution centre shows that

- (a) Assessments on each of the international distribution centre's performance with respect to each criterion are presented subjectively by multiple decision makers as it is difficult to give exact numerical values (Wibowo and Deng, 2009).
- (b) The criteria importance used for the international distribution centre evaluation and selection process is presented subjectively which is subject to the preferences of the decision makers, and is hard to determine accurately. The process of assigning equal weights to all criteria under consideration is undesirable as it leads to an inconsistent decision outcome (Yeh et al., 2010).

- (c) The evaluation criteria are generally multi-dimensional in nature and a simultaneous consideration of those multiple criteria is required for making effective selection decisions (Wibowo and Deng, 2009; Wibowo and Deng, 2010b).
- (d) The decision makers are faced with the problem of aggregating individual preferences in order to achieve an agreed decision outcome which is cognitively demanding on the decision makers (Wibowo and Deng, 2009).

Based on the characteristics of the international distribution centre evaluation and selection problem, it is therefore necessary to apply the DSS approach developed in Chapter 5 for solving the international distribution centre evaluation and selection problem. The DSS approach is capable for effectively solving the international distribution centre evaluation and selection process in which both the criteria importance and alternative performance are presented subjectively by multiple decision makers. As a result, effective decisions can be made based on the proper consideration of the decision makers' subjective assessments.

Based on the interviews conducted by the organization, the assessment results with respect to each criterion are obtained. To facilitate the making of subjective performance assessments, linguistic variables shown in Table 3.1 are used effectively to handle the subjectiveness and imprecision of the decision making process. Table 9.1 show the performance assessments results of international distribution centre alternatives provided by the decision makers.

**Table 9.1 Performance Assessments of International Distribution Centre Alternatives**

Alternatives	Decision Makers	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$C_6$
$A_1$	$D_1$	VP	G	G	P	G	P
	$D_2$	G	G	VG	G	G	VP
	$D_3$	G	F	G	VG	F	F
$A_2$	$D_1$	P	G	F	G	F	G
	$D_2$	P	VP	G	F	F	VP
	$D_3$	VP	F	F	G	G	G
$A_3$	$D_1$	G	VP	G	G	F	VP
	$D_2$	P	VG	G	F	F	P
	$D_3$	F	P	G	VG	VP	P
$A_4$	$D_1$	P	G	F	G	F	G
	$D_2$	G	G	F	P	G	VP
	$D_3$	G	P	VP	G	P	VG
$A_5$	$D_1$	F	G	G	P	VG	VP
	$D_2$	P	G	VG	G	F	G
	$D_3$	VG	F	G	VP	F	G
$A_6$	$D_1$	VP	VG	F	VG	G	VG
	$D_2$	G	F	G	VG	G	F
	$D_3$	G	VG	G	G	F	VG
$A_7$	$D_1$	G	G	F	P	VG	G
	$D_2$	G	F	VG	F	G	VP
	$D_3$	G	G	F	P	G	G
$A_8$	$D_1$	G	F	VP	G	F	VP
	$D_2$	F	G	F	G	VP	VP
	$D_3$	G	VG	G	G	F	G
$A_9$	$D_1$	P	G	P	G	F	F
	$D_2$	F	G	G	F	P	G
	$D_3$	G	G	G	F	P	F

Based on the linguistics variables used by the weighting vectors as defined in Table 3.1, the criteria weights for selecting the international distribution centres can be obtained directly from the decision makers. Table 9.2 shows the criteria weights for the criteria. Based on the obtained fuzzy criteria weights and fuzzy performance ratings, the overall objective of the selection problem is to apply the DSS approach developed in Chapter 5 to aggregate the fuzzy criteria weights and fuzzy performance ratings in order to produce the overall performance index for each international distribution centre.

**Table 9.2 Criteria Weights for International Distribution Centre Alternatives**

Criteria	Criteria Weights		
	$D_1$	$D_2$	$D_3$
$C_1$	VH	VH	H
$C_2$	M	M	M
$C_3$	H	H	H
$C_4$	M	L	M
$C_5$	L	VH	VH
$C_6$	VH	M	L

## 9.4 Results and Discussion

An analysis of the requirements of the international distribution centre evaluation and selection problem described as above reveals that (a) multiple decision makers are involved in the decision making process, (b) all the decision makers' assessments on criteria weights and performance ratings are linguistic terms represented by fuzzy numbers, (c) simultaneous consideration of those multiple criteria is required for making effective selection decisions,

and (d) the size of the problem is quite large. Existing approaches for dealing with this class of decision situations are found to be ineffective in (a) addressing the needs of multiple decision makers and multiple criteria, (b) modelling the subjectiveness and imprecision of the human decision making process, and (c) reducing cognitive demand on the decision makers in the process. (Deng, 2005; Yeh et al., 2010).

To effectively handle the international distribution centre evaluation and selection problem, a DSS approach capable of dealing with subjective assessments from multiple decision makers in a simple and straightforward manner is desirable. The DSS approach is appropriate for dealing with this type of decision problem due to its simplicity and efficient computation.

The selection process start with the determination of the membership functions as defined in Table 3.1 for the linguistic terms used in Table 9.1 for the fuzzy decision matrix and Table 9.2 for the fuzzy weight vector. The overall fuzzy decision matrix and the overall fuzzy weight vector of international distribution centre alternatives can then be calculated by (5.3) and (5.4) respectively. Table 9.3 shows the calculation results.

Based on the results in Table 9.3, the weighted fuzzy performance matrix can be obtained by multiplying the fuzzy decision matrix by the fuzzy weighting vector. Table 9.4 shows the weighted fuzzy performance matrix that represents the overall performance of each international distribution centre alternative on each criterion.



**Table 9.3 The Overall Fuzzy Decision Matrix and the Overall Fuzzy Weight Vector of International Distribution Centre Alternatives**

Alternatives	Criteria					
	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$C_6$
$A_1$	(5.67, 7.67, 9)	(4.33, 6.33, 8.33)	(5.67, 7.67, 9)	(4.33, 6.33, 7.67)	(4.33, 6.33, 8.33)	(1.67, 3, 5)
$A_2$	(1, 2.33, 4.33)	(3, 4.33, 6.33)	(3.67, 5.67, 7.67)	(4.33, 6.33, 8.33)	(3.67, 5.67, 7.67)	(3.67, 5, 7)
$A_3$	(3, 5, 7)	(5, 7, 7.67)	(5, 7, 9)	(5, 7, 8.33)	(2.33, 3.67, 5.67)	(1, 1.67, 3.67)
$A_4$	(3.67, 5.67, 7.67)	(3.67, 5.67, 7.67)	(2.33, 3.67, 5.67)	(3.67, 5.67, 7.67)	(3, 5, 7)	(4.33, 5.67, 7)
$A_5$	(3.67, 5.67, 7)	(4.33, 6.33, 8.33)	(5.67, 7.67, 9)	(2.33, 3.67, 5.67)	(4.33, 6.33, 7.67)	(3.67, 5, 7)
$A_6$	(3.67, 5, 7)	(5.67, 7.67, 8.33)	(4.33, 6.33, 8.33)	(6.33, 8.33, 9)	(4.33, 6.33, 8.33)	(5.67, 7.67, 8.33)
$A_7$	(5, 7, 9)	(4.33, 6.33, 8.33)	(4.33, 6.33, 7.67)	(1.67, 3.67, 5.67)	(5.67, 7.67, 9)	(3.67, 5, 7)
$A_8$	(4.33, 6.33, 8.33)	(5, 7, 8.33)	(3, 4.33, 6.33)	(5, 7, 9)	(2.33, 3.67, 5.67)	(2.33, 3, 5)
$A_9$	(3, 5, 7)	(5, 7, 9)	(3.67, 5.67, 7.67)	(3.67, 5.67, 7.67)	(1.67, 3.67, 5.67)	(3.67, 5.67, 7.67)
Criteria Weights	(6.33, 8.33, 9)	(3, 5, 7)	(5, 7, 9)	(2.33, 4.33, 6.33)	(5, 7, 7.67)	(3.67, 5.67, 7)

**Table 9.4 The Weighted Fuzzy Performance Matrix of International Distribution Centre Alternatives**

Alternatives	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$C_6$
$A_1$	(35.91, 63.92, 81)	(12.99, 31.65, 58.31)	(28.35, 53.69, 81)	(10.10, 27.43, 48.58)	(21.65, 44.31, 63.86)	(6.12, 17, 35)
$A_2$	(6.33, 19.42, 38.97)	(9, 21.65, 44.31)	(18.35, 39.69, 69.03)	(10.10, 27.43, 52.76)	(18.35, 39.69, 58.80)	(13.46, 28.33, 49)
$A_3$	(19, 41.67, 63)	(15, 35, 53.69)	(25, 49, 81)	(11.67, 30.33, 52.76)	(11.65, 25.69, 43.47)	(3.67, 9.46, 25.69)
$A_4$	(23.24, 47.25, 69.03)	(11.01, 28.35, 53.69)	(11.65, 25.69, 51.03)	(8.56, 24.57, 48.58)	(15, 35, 53.67)	(15.88, 32.13, 49)
$A_5$	(23.24, 42.75, 63)	(12.99, 31.65, 58.31)	(28.35, 53.69, 81)	(5.44, 15.90, 35.91)	(21.65, 44.31, 58.80)	(13.46, 28.33, 49)
$A_6$	(23.24, 41.67, 63)	(17.01, 38.35, 58.31)	(21.65, 44.31, 74.97)	(14.77, 36.10, 57)	(21.65, 44.31, 63.86)	(20.79, 43.46, 58.31)
$A_7$	(31.67, 58.33, 81)	(12.99, 31.65, 58.31)	(21.65, 44.31, 69.03)	(3.89, 15.90, 35.91)	(28.35, 53.69, 69)	(13.46, 28.33, 49)
$A_8$	(27.42, 52.75, 74.97)	(15, 35, 58.31)	(15, 30.31, 56.97)	(11.67, 30.33, 57)	(11.65, 25.69, 43.47)	(8.54, 17, 35)
$A_9$	(19, 41.67, 63)	(15, 35, 63)	(18.35, 39.69, 69.03)	(8.56, 24.57, 48.58)	(8.35, 25.69, 43.47)	(13.46, 32.13, 53.69)

The fuzzy maximum ( $M_{\max}^j$ ) and fuzzy minimum ( $M_{\min}^j$ ) with respect to each criterion across all international distribution centre alternatives can then be determined by (5.10) and (5.11) respectively based on Table 9.4. Table 9.5 shows the results for the fuzzy maximum and fuzzy minimum.

**Table 9.5 The Fuzzy Maximum and the Fuzzy Minimum**

Criteria	Fuzzy maximum ( $M_{\max}^j$ )	Fuzzy minimum ( $M_{\min}^j$ )
$C_1$	(6.33, 81, 81)	(6.33, 6.33, 81)
$C_2$	(9, 63, 63)	(9, 9, 63)
$C_3$	(11.65, 81, 81)	(11.65, 11.65, 81)
$C_4$	(3.89, 57, 57)	(3.89, 3.89, 57)
$C_5$	(8.35, 69, 69)	(8.35, 8.35, 69)
$C_6$	(3.67, 69, 69)	(3.67, 3.67, 69)

The degree of dominance ( $d_{ij}^+$ ) of the fuzzy maximum over the weighted fuzzy performance of each project alternative, and the degree of dominance ( $d_{ij}^-$ ) of the weighted fuzzy performance of each alternative over the fuzzy minimum across all criteria can be calculated by (5.12)-(5.15). Table 9.6 shows the results.

**Table 9.6      The Degree of Dominance Across International Distribution Centre Alternatives**

	Alternatives	$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$C_6$
$d_{ij}^+$	$A_1$	4.17	10.68	30.27	5.04	10.27	6.89
	$A_2$	34.54	20.01	15.53	6.43	7.05	1.55
	$A_3$	14.89	10.44	12.45	7.40	2.73	12.5
	$A_4$	9.60	13.98	5.31	4.09	3.77	2.82
	$A_5$	11.61	10.68	14.01	3.02	8.59	1.55
	$A_6$	13.47	7.11	8.88	10.74	10.27	9.71
	$A_7$	0.89	10.68	6.9	3.03	15.11	1.55
	$A_8$	4.37	8.90	1.79	8.81	2.73	6.89
	$A_9$	4.40	7.33	5.36	4.09	2.73	4.38
$d_{ij}^-$	$A_1$	2.32	7.32	7.15	22.74	30.49	14.89
	$A_2$	9.65	2.01	7.59	24.14	27.26	23.33
	$A_3$	10.01	7.56	35.57	25.10	17.49	9.27
	$A_4$	15.29	4.01	17.81	21.79	23.99	24.60
	$A_5$	13.28	7.32	37.13	14.68	28.80	23.33
	$A_6$	11.42	10.89	31.99	28.44	30.49	31.48
	$A_7$	25.78	7.31	30.01	14.68	35.33	23.33
	$A_8$	20.49	9.11	21.33	26.52	17.49	14.89
	$A_9$	20.49	10.67	28.47	21.79	17.49	26.16

The degree of dominance that the positive fuzzy ideal solution has on each alternative  $A_i$  and the degree of dominance that each alternative  $A_i$  has on the negative fuzzy ideal solution can then be determined by (5.16) and (5.17) respectively. Table 9.7 shows the results of the degree of dominance for international distribution centre alternatives.

**Table 9.7 The Degree of Dominance for International Distribution Centre Alternatives**

$A_i$	$d_i^+$	$d_i^-$
$A_1$	67.32	84.91
$A_2$	85.11	93.98
$A_3$	60.41	105.01
$A_4$	39.57	107.49
$A_5$	49.46	124.54
$A_6$	60.18	144.71
$A_7$	38.16	136.44
$A_8$	33.49	109.83
$A_9$	28.29	125.07

The overall performance index for each international distribution centre alternative across all the criteria can be calculated by applying (5.18) to the data in Table 9.7. Table 9.8 shows the overall performance index values of the international distribution centre alternatives and their corresponding rankings. Alternative  $A_9$  is the most suitable international distribution centre alternative with the overall performance index value of 0.951.

The study suggests that the application of the DSS approach is efficient and effective for dealing with the uncertain and imprecise nature of the evaluation and selection process faced

by multiple decision makers in the international distribution centre evaluation and selection problem.

**Table 9.8      The Overall Performance Index and Ranking of International Distribution Centre Alternatives**

Alternative	Performance Index	Ranking
$A_1$	0.614	8
$A_2$	0.549	9
$A_3$	0.751	7
$A_4$	0.881	4
$A_5$	0.864	5
$A_6$	0.853	6
$A_7$	0.927	2
$A_8$	0.915	3
$A_9$	0.951	1

Sensitivity analysis can be conducted through changing the subjective assessments of the decision makers with respect to the decision variables when no clear-cut decisions are present. With the simplicity in concept underlying the approach, the decision makers can interactively explore the problem in different manners so that a better understanding of the problem and the relationships between the decision and its parameters can be obtained. This would further improve the confidence of the decision makers in the selection process.

## **9.5 Concluding Remarks**

The international distribution centre evaluation and selection process is complex and challenging due to the presence of multiple decision makers, numerous selection criteria, and subjectiveness and imprecision inherent in the human decision making process. The existence of subjectiveness and imprecision is because it is common for the decision makers to make subjective assessments with respect to the criteria importance and the international distribution centre's performance with respect to each criterion in the problem solving process. To effectively solve this problem, this chapter has formulated the international distribution centre evaluation and selection problem as a multicriteria group decision making problem and applied the DSS approach developed in Chapter 5 to address the evaluation and selection problem.

The result shows that the DSS approach applied to solve the international distribution centre evaluation and selection problem is capable of adequately handling the subjectiveness and imprecision inherent in the international distribution centre evaluation and selection process. The DSS approach is found to be effective and efficient, due to the comprehensibility of its underlying concepts and the straightforward computation process. In particular, the use of this approach greatly reduces the decision makers' cognitive burden in the decision making process and further improves the consistency of the decision makers' decisions.

## Chapter 10

# Consensus Based Supplier Evaluation and Selection

### 10.1 Introduction

In today's highly competitive environment characterized by low profit margins, selecting the most suitable supplier in a given situation is of strategic importance to the sustainable development of every organization (Tahriri et al., 2008; Wibowo and Deng, 2009). This is because the most suitable supplier greatly helps organizations create and maintain their competitive advantages through reducing the material purchasing cost, improving the delivery time of finished products, and increasing the quality of their products. As a result, selecting the most suitable supplier from available suppliers becomes a critical problem in modern organizations (Lee, 2009; Wibowo and Deng, 2009; Ho et al., 2010).

To make effective decisions while adequately considering the interest of different stakeholders in the supplier selection process, several decision makers are usually present (Ho et al., 2010), and multiple selection criteria have to be simultaneously considered (Ben-Arieh and Chen, 2006; Sreekumar and Mahapatra, 2009). To ensure the acceptance of the decision, a certain level of consensus among the decision makers has to be achieved. As a result, multicriteria consensus decision making is critical.

Developing consensus in multicriteria group decision making is complex due to (a) existence of various opinions of decision makers on individual issues, (b) use of subjective and



imprecise assessments, and (c) the cognitively demanding nature of the decision making process (Herrera-Viedma et al., 2005). To facilitate consensus building in the supplier evaluation and selection process, it is therefore desirable to apply a structured approach capable of comprehensively considering the requirements of decision makers while effectively modelling the subjectiveness and imprecision of the human decision making process.

This chapter formulates the supplier evaluation and selection problem as a multicriteria group decision making problem and applies the consensus based approach developed in Chapter 6 for solving the problem in an efficient and effective manner. Based on the requirements of the problem situation in the supplier evaluation and selection, the consensus based approach is applied for effectively dealing with this practical multicriteria group decision making problem.

## **10.2 Suppliers Evaluation and Selection in Taiwan**

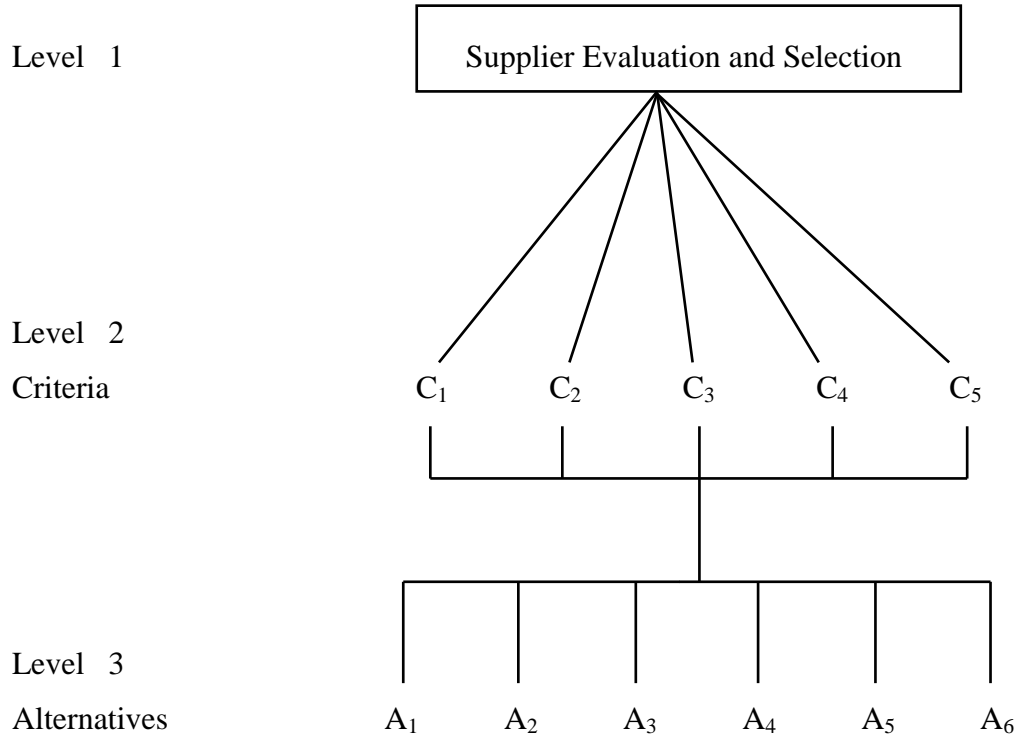
The thin film transistor liquid crystal display (TFT-LCD) industry is becoming the fastest growing industry in Taiwan (Chang, 2005). In fact, Taiwan is currently the world's largest supplier of TFT-LCDs, and produces more than 40% of the world's supply (Hung, 2006). Research has shown that by 2005, there were 123 companies in Taiwan's flat-panel display industry, creating a value of US\$15.49 billion, of which TFT-LCDs accounted for around 66% (Lee, 2009).

As the global TFT-LCD industry enters the mature stage, an extremely competitive and cost-cutting war is foreseeable. Taiwan's competitiveness originates from the advantages of quality, cost, flexibility and semiconductor manufacturing industry. Therefore, how to produce the products with a lower cost, better quality at the right time and place is essential for Taiwan's TFT-LCD manufacturers to maintain a competitive edge and make a decent profit (Lee, 2009).

To remain competitive in the market, a leading TFT-LCD manufacturer in Taiwan is considering the most suitable supplier that would meet the requirements of the manufacturer to achieve cost-reduction, ensure product availability, obtain leading-technology product, and maintain competitiveness in the market.

The supplier selection process usually affects several functions in the organization. Therefore, such a decision should be made according to the consensus of a cross-functional team of decision makers with various points of views and who represent different services of the company. In this situation, a project team consisting of three decision makers from purchasing, finance and corporate development departments is formed.

This team has identified several potential suppliers and evaluation and selection criteria through a comprehensive investigation. Six alternative suppliers and five selection criteria are identified for evaluating the most suitable supplier for selection. These selection criteria include Financial Attractiveness ( $C_1$ ), Quality Expectation ( $C_2$ ), Delivery Capability ( $C_3$ ), Organizational Alignment ( $C_4$ ), and Technical Capacity ( $C_5$ ). The hierarchical structure of supplier evaluation and selection problem is shown in Figure 10.1.



Legend:

$C_1$ : Financial Attractiveness

$C_2$ : Quality Expectation

$C_3$ : Delivery Capability

$C_4$ : Organizational Alignment

$C_5$ : Technical Capacity

$A_i$  ( $i = 1, 2, \dots, n$ ): Alternative Suppliers.

**Figure 10.1 The Hierarchical Structure of the Supplier Evaluation and Selection Problem**

Financial Attractiveness ( $C_1$ ) refers to the subjective assessment of the decision maker on the financial consideration associated with individual suppliers (Talluri et al., 2006; Chou and Chang, 2008) with respect to the resource limitation of an organization and its business strategy. This is often measured by unit price of the product, freight cost for delivering the

product, and cost reduction plan which comes in the form of percentage discount margins that a supplier provides for the organization on an annual basis.

Quality Expectation ( $C_2$ ) refers to the subjective assessment of the decision maker on the level of achievement of the supplied goods to meet or exceed the organization's expectations. This is often measured by interval rejection rate which refers to the ratio of defective units found by the supplier, customer rejection rate which refers to the ratio of defective units found by the customer, and yield rate (Gheidar Kheljani et al., 2009).

Delivery Capability ( $C_3$ ) refers to the subjective assessment of the decision maker on both the suppliers' logistical capabilities and critical activities that are performed from the time that the products are ordered until they arrive. It is an important issue that it influences costs, speed to market and value perception by end user as delayed deliveries can disrupt operational efficiency (Sreekumar and Mahapatra, 2009). This is often measured by order lead-time in terms of the number of days from order placement to the receipt of the products, delivery reliability, and distribution network quality.

Organizational Alignment ( $C_4$ ) reflects the subjective assessment of the decision maker on how individual suppliers serve the business strategy and organizational objectives in the long term (Deng and Wibowo, 2004). This is often measured by the management capability of the supplier, and the strategic fit which considers the fit between the organization's strategy and the supplier's strategy.

Technical Capacity ( $C_5$ ) involves the subjective assessment of the management of an organization towards the technical capabilities of a supplier with respect to its products and

services delivered (Chen, 2000; Yeh et al., 2000). This is assessed by innovation to develop new products or techniques and improve existing products, technical problem solving due to unexpected problems, and cost reduction capability in production.

Based on the discussion above, it is observed that the supplier selection process affects several functions in the organization. To ensure the acceptance of the decision, a certain level of consensus among the decision makers has to be achieved. To facilitate consensus building in the supplier evaluation and selection process, it is therefore desirable to apply a structured approach capable of comprehensively considering the requirements of decision makers while effectively modelling the subjectiveness and imprecision of the human decision making process.

### **10.3 Data Collection**

A comprehensive investigation has been carried out to collect the required data from various decision makers for the evaluation process. Subjective assessments are usually involved in evaluating the performance of alternative suppliers and the importance of the selection criteria. To facilitate the subjective evaluation process, linguistic variables are used for representing the subjective assessments of the decision makers. To ensure the efficiency of the computation process for making the selection decision, fuzzy numbers are used to approximate the linguistic variables in the evaluation process.

It is observed that three issues are involved in this supplier evaluation and selection process. The evaluation criteria are generally multi-dimensional in nature and a simultaneous

consideration of those multiple criteria is required for making effective selection decisions. The evaluation process involves subjective assessments, resulting in qualitative and vague data being used. Multiple decision makers are present in the evaluation process and a certain level of agreement among the decision makers is critical for facilitating the acceptance of the decision made.

It is therefore necessary to apply the consensus based approach developed in Chapter 6 for effectively solving the supplier evaluation and selection problem involving multiple decision makers. The approach is capable for effectively solving the supplier evaluation and selection problem involving several decision makers, multiple selection criteria, and the presence of subjective and imprecise assessments while incorporating the consensus building process. As a result, effective decisions can be made based on the proper consideration of the interest of different decision makers in the supplier evaluation and selection process.

Based on the data collected by the organization, the assessment results with respect to each criterion are obtained. To model the subjectiveness and imprecision in the supplier evaluation and selection process, fuzzy numbers denoted as  $(a_1, a_2, a_3)$  where  $a_1 < a_2 < a_3$  are used to represent the subjective assessment of the decision makers. Table 10.1 shows the performance assessments and criteria weights results of alternative suppliers from various decision makers.

**Table 10.1 Performance Assessments of Alternative Suppliers and Criteria Weights**

	Decision Makers	Criteria				
		$C_1$	$C_2$	$C_3$	$C_4$	$C_5$
Supplier $A_1$	$D_1$	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)
	$D_2$	(7,9,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)
	$D_3$	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(1,3,5)
Supplier $A_2$	$D_1$	(1,3,5)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)
	$D_2$	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)
	$D_3$	(1,3,5)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)
Supplier $A_3$	$D_1$	(7,9,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)
	$D_2$	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)
	$D_3$	(7,9,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)
Supplier $A_4$	$D_1$	(7,9,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)
	$D_2$	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(1,3,5)
	$D_3$	(5,7,9)	(5,7,9)	(3,5,7)	(1,3,5)	(5,7,9)
Supplier $A_5$	$D_1$	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)
	$D_2$	(1,3,5)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)
	$D_3$	(3,5,7)	(1,3,5)	(5,7,9)	(1,3,5)	(7,9,9)
Supplier $A_6$	$D_1$	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(1,3,5)
	$D_2$	(7,9,9)	(3,5,7)	(5,7,9)	(1,3,5)	(7,9,9)
	$D_3$	(7,9,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)
Criteria Weights	$D_1$	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(1,3,5)
	$D_2$	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)	(7,9,9)
	$D_3$	(7,9,9)	(7,9,9)	(3,5,7)	(5,7,9)	(5,7,9)

In this situation, the decision makers have agreed to assign the consensus threshold value to be 0.70. Based on the obtained fuzzy criteria weights and fuzzy performance ratings from the decision makers, the overall objective of the selection problem is to calculate the degree of similarity between individual decision makers' fuzzy assessments and the group fuzzy assessments for the performance ratings and the criteria weights with respect to each criterion for consensus building, and aggregate the fuzzy criteria weights and fuzzy performance ratings in order to produce the overall performance index for each supplier alternative.

## **10.4 Results and Discussion**

The discussion above shows that (a) multiple decision makers are involved, (b) subjective assessments are present in the decision making process, (c) triangular fuzzy numbers are used to represent the subjective assessment of the decision makers, and (d) the alternatives' performance ratings and the criteria weights need to be assessed through a consensus building process. To deal with this kind of evaluation and selection problem situation, the consensus based approach developed in Chapter 6 is suitable for effectively handling this problem.

To understand the degree of consensus among the decision makers, the concept of similarity is introduced. The degree of similarity between individual decision maker's fuzzy assessments and the group fuzzy assessments for both the performance ratings and criteria weights can be calculated using (6.5) and (6.6). The results are shown in Table 10.2. This similarity measure is beneficial towards consensus building process as the value obtained from the similarity measure is used to guide the decision makers in the direction of the changes in their opinions in order to increase the consensus level (Wibowo and Deng, 2009).



To ensure the level of agreement between the decision maker's preferences is consistent, a consistency index (CI) is established. This CI is used to identify whether the preferences provided by individual decision makers are of acceptable consistency to the specified consensus threshold predetermined by the group decision makers. This is done by allocating an agreed CI value by the group decision makers and by comparing the agreed group value to the calculated value of an individual decision maker. If the CI value of an individual decision maker is lower than the specified consensus threshold, the decision maker concerned has to adjust his/her assessments.

This process is a consensus building process as it continuously requests decision makers to modify their assessments until all the CI values of individual decision makers are higher than the specified consensus threshold. The CI of individual decision makers with respect the performance ratings and the criteria weights for all suppliers can be calculated using (6.7). Table 10.3 shows the calculation results. It can be observed from Table 10.3 that the assessments provided by decision makers are higher than the pre-defined consensus threshold value of 0.70. Therefore, the consensus process is finalized. Otherwise, the system will request the decision maker concerned to modify his/her assessments.

**Table 10.2 The Degree of Similarity of Decision Makers**

	Decision Makers	Criteria				
		$C_1$	$C_2$	$C_3$	$C_4$	$C_5$
Supplier $A_1$	$D_1$	1	1	1	0.64	0.64
	$D_2$	0.64	0.81	0.73	0.89	0.78
	$D_3$	0.67	0.70	0.87	0.73	0.67
Supplier $A_2$	$D_1$	0.94	0.81	0.85	0.82	0.63
	$D_2$	0.94	0.76	0.79	0.94	0.55
	$D_3$	0.94	0.71	0.82	0.71	0.55
Supplier $A_3$	$D_1$	0.67	0.53	0.47	0.70	0.55
	$D_2$	1	1	1	0.64	0.64
	$D_3$	0.64	0.81	0.73	0.89	0.78
Supplier $A_4$	$D_1$	0.64	0.81	0.73	0.89	0.78
	$D_2$	0.67	0.70	0.87	0.73	0.67
	$D_3$	0.82	0.82	0.68	0.81	0.80
Supplier $A_5$	$D_1$	0.94	0.76	0.79	0.94	0.55
	$D_2$	0.94	0.71	0.89	0.66	0.55
	$D_3$	0.67	0.57	0.47	0.77	0.79
Supplier $A_6$	$D_1$	0.76	0.79	0.94	0.65	0.67
	$D_2$	0.76	0.79	0.94	0.76	0.78
	$D_3$	0.67	0.53	0.47	0.70	0.66
Criteria Weights	$D_1$	0.94	1	0.72	0.94	0.76
	$D_2$	0.82	1	0.71	0.55	0.77
	$D_3$	0.72	1	0.72	0.77	0.76

**Table 10.3 The Consistency Index of Individual Decision Makers**

	Decision Makers	Consistency Index
Supplier $A_1$	$D_1$	0.94
	$D_2$	0.82
	$D_3$	0.72
Supplier $A_2$	$D_1$	0.76
	$D_2$	0.84
	$D_3$	0.81
Supplier $A_3$	$D_1$	0.73
	$D_2$	0.84
	$D_3$	0.79
Supplier $A_4$	$D_1$	0.87
	$D_2$	0.81
	$D_3$	0.75
Supplier $A_5$	$D_1$	0.73
	$D_2$	0.81
	$D_3$	0.78
Supplier $A_6$	$D_1$	0.82
	$D_2$	0.72
	$D_3$	0.75

Once consensus has been reached, the weighted fuzzy performance matrix that represents the overall performance of each alternative on each criterion can be determined by multiplying the fuzzy criteria weights by the alternatives' fuzzy performance ratings. Table 10.4 shows the weighted fuzzy performance matrix that represents the overall performance of each supplier on each criterion.

**Table 10.4 The Weighted Fuzzy Performance Matrix of Suppliers**

Criteria	Supplier $A_1$	Supplier $A_2$	Supplier $A_3$	Supplier $A_4$	Supplier $A_5$	Supplier $A_6$
$C_1$	(32.11, 58.78, 75)	(13.22, 33.22, 57)	(39.67, 69, 81)	(28.33, 53.67, 75)	(17, 38.33, 63)	(35.89, 63.89, 81)
$C_2$	(18.33, 39.67, 53.67)	(35, 63, 69)	(21.67, 44.33, 58.78)	(15, 35, 53.67)	(25, 49, 58.78)	(21.67, 44.33, 58.78)
$C_3$	(21.67, 44.33, 69.44)	(27.44, 52.78, 75)	(24.56, 48.56, 75)	(15.89, 35.89, 63.89)	(27.44, 52.78, 75)	(24.56, 48.46, 75)
$C_4$	(18.78, 40.11, 63.89)	(24.56, 48.56, 75)	(24.56, 48.56, 75)	(10.11, 27.44, 52.78)	(18.78, 40.11, 63.89)	(15.89, 35.89, 63.89)
$C_5$	(18.33, 39.67, 63.89)	(21.67, 44.33, 63.89)	(15, 35, 52.78)	(15, 35, 58.33)	(15, 35, 58.33)	(31.67, 58.33, 75)

Based on (6.8) - (6.16), the Hamming distance between alternative  $A_i$  and the positive ideal solution and the negative solution can be calculated respectively. The results are shown in Table 10.5.

**Table 10.5 The Hamming Distance Between Each Supplier Alternative and the Ideal Solutions**

$A_i$	$s_i^+$	$s_i^-$
$A_1$	1.88	1.37
$A_2$	0.52	1.96
$A_3$	1.29	2.30
$A_4$	1.07	1.25
$A_5$	0.83	2.27
$A_6$	0.64	1.57

The overall performance index value of each supplier across all the criteria can then be obtained by applying (6.17) to the data in Table 10.5. Table 10.6 shows the overall performance index values of the supplier alternatives and their corresponding rankings. Table 10.6 shows that supplier  $A_2$  is the obvious choice for selection as it has the highest performance index value of 0.79.

**Table 10.6 The Overall Performance Index and Ranking of Suppliers**

Suppliers	Performance Index	Ranking
$A_1$	0.58	5
$A_2$	0.79	1
$A_3$	0.64	4
$A_4$	0.54	6
$A_5$	0.73	2
$A_6$	0.71	3

The study suggests that the consensus based approach developed in Chapter 6 is capable for effectively handling the multi-dimensional nature of the selection process and the presence of subjectiveness and imprecision in supplier evaluation and selection problem, reducing the cognitively demanding nature of the evaluation and selection process on the decision makers, and considering the interest of different decision makers through consensus building in the evaluation and selection process.

## **10.5 Concluding Remarks**

The supplier evaluation and selection process is complex as it involves several decision makers, multiple selection criteria, numerous suppliers, the presence of subjective and imprecise assessments, and the pressure to consider all multiple evaluation criteria simultaneously in a timely manner. In addition to these complex issues associated with the supplier evaluation and selection problem, it is critical to reach a certain level of agreement among the decision makers in selecting suppliers for facilitating the acceptance of the decision made. As a result, a structured group decision making approach that is capable of effectively solving the supplier evaluation and selection problem is desirable.

This chapter has presented an empirical study on the TFT-LCD manufacturer in Taiwan to exemplify applicability of the consensus based approach developed in Chapter 6 for effectively solving the supplier evaluation and selection problem under uncertainty. It is shown that the approach has a number of advantages for solving the supplier evaluation and selection problem including the capability to adequately handle the group decision making process, and the ability to deal with the subjectiveness and imprecision inherent in the

supplier evaluation and selection problem. The merit of this approach includes its simplicity in concept and the efficiency in computation.

## **Chapter 11**

# **A Risk-Oriented Approach for Evaluating and Selecting Hotel Locations under Uncertainty**

### **11.1 Introduction**

The tourism industry is the fastest growing industry in the 21<sup>st</sup> century (Fatma and Timothy, 2005). Recent surveys have indicated that tourism is currently a major contributor in global economic development (Johnson and Vanetti, 2005; Pan, 2005; Hsieh and Lin, 2010). According to the Taiwanese Tourism Bureau, 46.09% of the expenditures from tourists are made within their hotels (Hsieh and Lin, 2010). This statistic reflects the importance of the hotel sector in the tourism industry development and shows that international tourist hotels will clearly benefit from this tourism industry. In fact, a forecast from the Pacific Asia Travel Association indicates that the tourism industry will be the fastest growing industry over the next decade (Chou et al., 2008). As a result, it is crucial for hotel entrepreneurs to take advantage of this growing demand from tourists by expanding their market share through new hotels development.

In order for hotel entrepreneurs to gain a competitive advantage in the establishment of new hotels, it is critical that the most suitable hotel location is selected. This is because the selection of the most suitable hotel location has important strategic implications including an increase in market share and profitability (Pan, 2005; Chou et al., 2008). In fact, numerous



researches have indicated that hotel location is the significant factor influencing operation performance in the future (Weng and Wang, 2004; Chou et al., 2008; Hung et al., 2010). As a result, evaluating and selecting the most suitable hotel location from many available hotel locations becomes a critical decision to be made in the tourism industry.

The challenge of evaluating and selecting the most suitable hotel location comes from two perspectives: (a) the involvement of multiple decision makers in the decision making process and (b) the need for an appropriate consideration of the potential risk due to the subjectiveness and imprecision existent in the human decision making process. To ensure effective decision outcomes of the hotel location evaluation and selection being made, it is important to adequately consider the potential risk in a specific decision making situation (Lam et al., 2007; Ritchie and Brindley, 2007; Wibowo and Deng, 2010a). This is due to the fact that decision makers' attitudes towards risk usually have a major effect on their decision behaviors, often resulting in different decisions being made (Wang and Elhag, 2006; Chen and Wang, 2009; Wibowo and Deng, 2009).

This chapter formulates the hotel location evaluation and selection problem as a multicriteria group decision making problem and applies the risk-oriented approach developed in Chapter 7 for solving the problem. By doing so, the chapter aims to demonstrate the applicability of the risk-oriented approach developed for adequately modelling the inherent risk in the multicriteria group decision making process and helping reduce the cognitively demanding nature of the evaluation and selection process on the decision makers.

## **11.2 The Hotel Location Evaluation and Selection**

The Asia Pacific region has been the rapidly growing tourism destination in the world (Pan, 2005). In fact, it has even surpassed the Americas to become the world's second-largest tourist-receiving region since 2001 (Weng and Wang, 2004). The 2006 annual report on tourism indicated that Taiwan had 29 tourist hotels with a total of 3298 rooms and 60 international tourist hotels with a total of 17,832 rooms (Chou et al., 2008). It is obvious that the number of hotels is not enough to meet the tourist demand. Owing to the significant growth of international tourism in the Asia Pacific region, the Taiwanese government is encouraging hotel entrepreneurs to expand their hotel operations in order to meet the demand of increasing annual tourists to Taiwan.

Against this background, a reputable hotel in Taiwan is planning to take this opportunity to build a new hotel for meeting the future demand from tourists. In order for the hotel to be successful in such an intensely competitive tourism marketplace, selecting the optimal location for the new hotel development is critical (Chou et al., 2008).

Two issues are usually concerned with the hotel location selection process. The hotel selection process usually involves multiple decision makers in the organization. Subjectiveness and imprecision is existent in the human decision making process requiring the need for an appropriate consideration of the potential risk. To ensure effective decision outcomes, it is important to adequately tackle these issues in a specific decision making situation.

The hotel location selection starts with the formation of a committee involving two academic experts and three professional hotel managers. This committee has identified several hotel location alternatives and the evaluation and selection criteria through a comprehensive investigation. Based on a thorough investigation by the committee, seven potential hotel location alternatives are identified. Four criteria are determined for evaluating and selecting the most suitable hotel location including Geographical Location ( $C_1$ ), Traffic Condition ( $C_2$ ), Hotel Facilities ( $C_3$ ), and Operational Convenience ( $C_4$ ) (Chou et al., 2009). Figure 11.1 shows the hierarchical structure of the hotel evaluation and selection problem.

Geographical Location ( $C_1$ ) refers to the subjective assessment of the decision maker on the strategic location of the hotel towards achieving its competitive advantage. It is often measured by the proximity of the location to public facilities, the distance to existing competitors, the public security around the location, the natural resources available, and the nearby rest facilities.

Traffic Condition ( $C_2$ ) focuses on the subjective assessment of the decision maker on the level of convenience of the situated hotel to various locations of interest. This is often measured by the distance to airport or freeway, the distance to downtown area, the distance to tourism scenic spots, the parking area, the convenience of freeway, the extensiveness of traffic routes, and the convenience to tourism scenic spots.

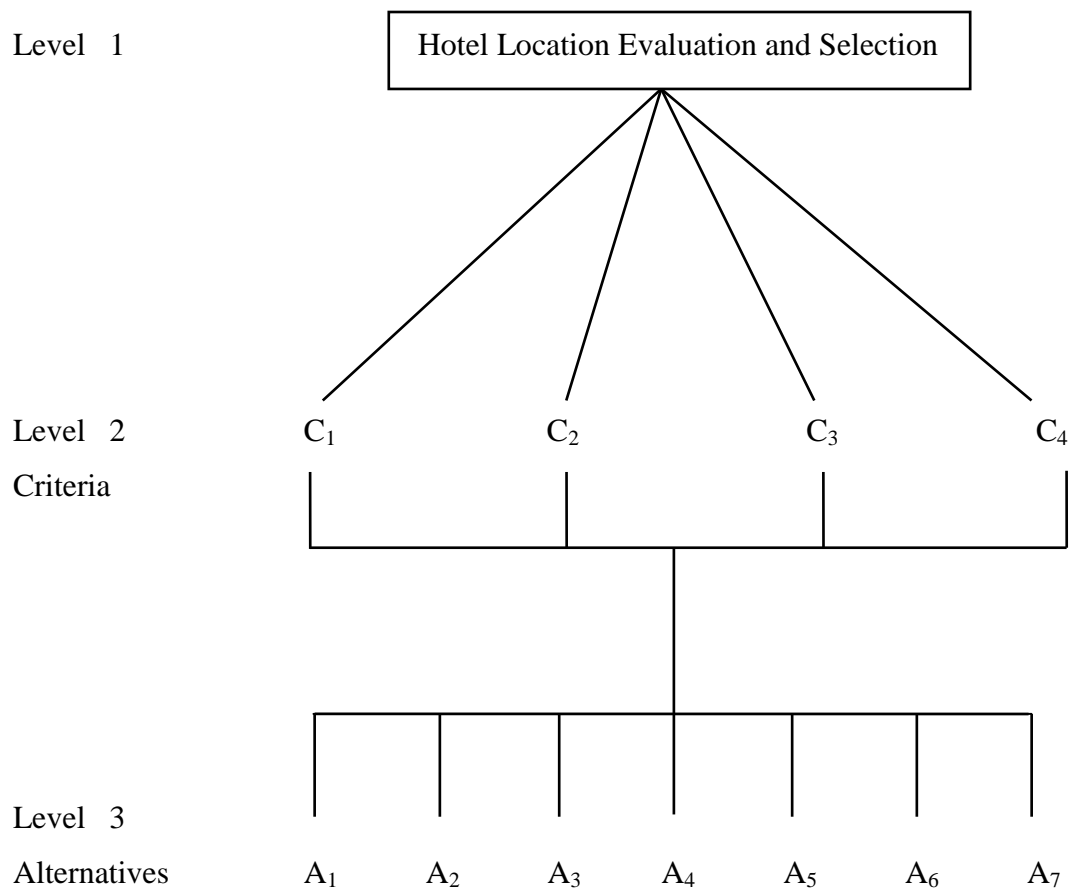
Hotel Facilities ( $C_3$ ) concern with the subjective assessment of the decision maker on the ability of the hotel to provide both facilities and services for fulfilling the requirements of the customer's expectations. This includes the indoor leisure facilities, the diversity of restaurants

in the hotel, the amalgamation with local culture, and the convenience of obtaining nearby land.

Operational Convenience ( $C_4$ ) involves with the subjective assessment of the decision maker on the key resources relevant for supporting the business operations of the hotel. This is assessed from the sufficiency of human resources, the quality of manpower available, the land cost, and the regulation restrictions.

Based on the discussion above, it can be seen that the hotel location evaluation and selection problem is challenging due to (a) the involvement of multiple decision makers in the decision making process, (b) the subjective assessments provided by the decision makers, and (c) the need for an appropriate consideration of the potential risk due to the subjectiveness and imprecision existent in the human decision making process.

To ensure effective decision outcomes of the hotel location evaluation and selection being made, it is important to adequately consider the potential risk in a specific decision making situation. This is due to the fact that decision makers' attitudes towards risk usually have a major effect on their decision behaviors, often resulting in different decisions being made. As a result, it is desirable to use a structured approach capable of adequately modelling the inherent risk in the multicriteria group decision making process and helping reduce the cognitively demanding nature of the evaluation and selection process on the decision makers.



Legend:

$C_1$ : Geographical Location

$C_2$ : Traffic Condition

$C_3$ : Hotel Facilities

$C_4$ : Operational Convenience

$A_i$  ( $i = 1, 2, \dots, n$ ): Alternative Hotel Locations

**Figure 11.1 The Hierarchical Structure for Hotel Location Evaluation and Selection**

## 11.3 Data Collection

The hotel location evaluation and selection process begins with assessing the performance of each hotel location with respect to each criterion, and with assessing the importance of these criteria. The actual experience in evaluating and selecting the most suitable hotel location shows that

- (a) Assessments on each of the hotel location performance with respect to each criterion are presented subjectively by multiple decision makers as it is difficult to give in a precise and yet consistent manner.
- (b) The criteria importance used for the hotel location evaluation and selection process is subject to the preference of the decision makers, and is hard to determine accurately. The process of assigning equal weights to all criteria under consideration is undesirable as it leads to an inconsistent decision outcome (Deng, 2005).
- (c) The decision problem requires effectively modelling the subjectiveness and imprecision in multicriteria group decision making in order to adequately handle the inherent risk.

To deal with these issues effectively, it is therefore necessary to apply the risk-oriented approach developed in Chapter 7 for solving the hotel location evaluation and selection problem. The risk-oriented approach is capable for adequately modelling the inherent risk in solving the hotel location evaluation and selection process where both the criteria importance and alternative performance are presented subjectively. As a result, effective decisions can be made based on adequately modelling the subjectiveness and imprecision in the human

decision making process while appropriately considering the interest of multiple decision makers at the same time.

Based on the interviews conducted by the organization, the assessment results with respect to each criterion are obtained. To facilitate the making of subjective performance assessments, linguistic variables of the criteria variables shown in Table 3.1 are used effectively to handle the subjectiveness and imprecision of the decision making process. Subjective assessments of the hotel location' performance with respect to each evaluation criterion can therefore be made in an efficient manner. Table 11.1 shows the performance assessments results of hotel location alternatives.

Based on the linguistics variables used by the weighting vectors as defined in Table 3.1, the criteria weights for selecting the hotel location can be obtained directly from the decision maker. Table 11.2 shows the relative importance of the criteria with respect to the overall objective of the problem. Based on the obtained fuzzy criteria weights and fuzzy performance ratings, the overall objective of the selection problem is to apply the risk-oriented approach developed in Chapter 7 to aggregate the fuzzy criteria weights and fuzzy performance ratings in order to produce the overall performance index for each hotel location.

**Table 11.1 Performance Assessments of Hotel Location Alternatives**

	Decision Makers	Criteria			
		$C_1$	$C_2$	$C_3$	$C_4$
Alternative $A_1$	$D_1$	G	VG	P	VG
	$D_2$	F	VG	F	G
	$D_3$	P	G	VG	VG
	$D_4$	F	F	G	F
	$D_5$	VG	G	VG	G
Alternative $A_2$	$D_1$	F	G	F	G
	$D_2$	VG	G	P	VG
	$D_3$	G	VG	G	G
	$D_4$	VG	G	G	G
	$D_5$	G	VG	VG	VG
Alternative $A_3$	$D_1$	VG	P	VG	VG
	$D_2$	F	G	P	G
	$D_3$	G	VG	VG	VG
	$D_4$	G	F	P	P
	$D_5$	F	VG	F	G
Alternative $A_4$	$D_1$	VG	G	F	G
	$D_2$	G	G	VG	VG
	$D_3$	F	VG	F	G
	$D_4$	G	G	G	G
	$D_5$	VG	G	VG	VG
Alternative $A_5$	$D_1$	G	G	P	VG
	$D_2$	F	G	F	G
	$D_3$	P	G	P	F
	$D_4$	G	P	G	F
	$D_5$	G	G	G	G
Alternative $A_6$	$D_1$	F	P	F	P
	$D_2$	G	F	G	P
	$D_3$	P	P	G	G
	$D_4$	P	G	F	P
	$D_5$	P	G	P	F
Alternative $A_7$	$D_1$	G	F	P	P
	$D_2$	G	VG	F	G
	$D_3$	VG	P	VG	VG
	$D_4$	F	G	P	G
	$D_5$	G	G	F	P

**Table 11.2 Weighting Vectors for the Criteria**

Criteria	Criteria Weights				
	$D_1$	$D_2$	$D_3$	$D_4$	$D_5$
$C_1$	H	VH	M	L	H
$C_2$	L	H	VH	H	H
$C_3$	VH	VH	H	VH	L
$C_4$	VH	M	H	M	H



## 11.4 Results and Discussion

An analysis of the requirements of the hotel location evaluation and selection problem described as above reveals that (a) multiple decision makers are involved in the evaluation and selection process, (b) all the decision makers' assessments on criteria weights and performance ratings are linguistic terms represented by fuzzy numbers, (c) the size of the problem is quite large, and (d) it is important to consider the potential risk in the evaluation and selection process. Existing approaches for dealing with this class of decision situations often require either (a) comparison of the fuzzy utilities for all alternatives involved or (b) transformation of the fuzzy data into a crisp format. The problems with these approaches are that they are (a) unable to adequately handle the inherent risk in the decision making process and (b) cognitively demanding on the decision makers in the evaluation process (Wibowo and Deng, 2010a).

To effectively handle the hotel location evaluation and selection problem, a risk-oriented approach capable of adequately handling the inherent risk in the decision making process in an effective manner is desirable. The risk-oriented approach is appropriate in dealing with the fuzzy data as the approach can satisfy the requirements of this specific problem based on its simplicity and efficient computation.

Using the membership functions defined in Table 3.1 for the linguistic terms used in Table 11.1 for the fuzzy decision matrix and Table 11.2 for the fuzzy weight vector, the weighted fuzzy performance matrix that represents the overall performance of each alternative on each criterion for each decision maker can be determined by multiplying (7.1) and (7.2). Table 11.3 show the calculation results.

**Table 11.3 The Weighted Fuzzy Performance Matrix of Hotel Location Alternatives**

	Decision	Criteria			
		$C_1$	$C_2$	$C_3$	$C_4$
Alternative $A_1$	$D_1$	(25, 49, 81)	(7, 27, 45)	(7, 27, 45)	(49, 81, 81)
	$D_2$	(21, 45, 63)	(35, 63, 81)	(21, 45, 63)	(15, 35, 63)
	$D_3$	(3, 15, 35)	(35, 63, 81)	(35, 63, 81)	(35, 49, 81)
	$D_4$	(3, 15, 35)	(15, 35, 63)	(35, 63, 81)	(9, 25, 49)
	$D_5$	(35, 63, 81)	(25, 49, 81)	(7, 27, 45)	(25, 49, 81)
Alternative $A_2$	$D_1$	(15, 35, 63)	(5, 21, 45)	(7, 27, 45)	(49, 81, 81)
	$D_2$	(49, 81, 81)	(25, 49, 81)	(7, 27, 45)	(21, 45, 63)
	$D_3$	(15, 35, 63)	(49, 81, 81)	(25, 49, 81)	(25, 49, 81)
	$D_4$	(7, 27, 45)	(25, 49, 81)	(35, 63, 81)	(15, 35, 63)
	$D_5$	(25, 49, 81)	(35, 63, 81)	(7, 27, 45)	(35, 63, 81)
Alternative $A_3$	$D_1$	(35, 63, 81)	(1, 9, 25)	(49, 81, 81)	(49, 81, 81)
	$D_2$	(21, 45, 63)	(25, 49, 81)	(7, 27, 45)	(15, 35, 63)
	$D_3$	(15, 35, 63)	(49, 81, 81)	(35, 63, 81)	(35, 63, 81)
	$D_4$	(5, 21, 45)	(5, 21, 45)	(7, 27, 45)	(3, 15, 35)
	$D_5$	(15, 35, 63)	(35, 63, 81)	(3, 15, 35)	(25, 49, 81)
Alternative $A_4$	$D_1$	(35, 63, 81)	(5, 21, 45)	(7, 27, 45)	(35, 63, 81)
	$D_2$	(35, 63, 81)	(25, 49, 81)	(49, 81, 81)	(21, 45, 63)
	$D_3$	(9, 25, 49)	(49, 81, 81)	(15, 35, 63)	(25, 49, 81)
	$D_4$	(5, 21, 45)	(25, 49, 81)	(35, 63, 81)	(15, 35, 63)
	$D_5$	(35, 63, 81)	(25, 49, 81)	(7, 27, 45)	(35, 63, 81)
Alternative $A_5$	$D_1$	(25, 49, 81)	(5, 21, 45)	(7, 18, 45)	(49, 81, 81)
	$D_2$	(21, 45, 63)	(25, 49, 81)	(21, 45, 63)	(15, 35, 63)
	$D_3$	(3, 15, 35)	(35, 63, 81)	(5, 21, 45)	(15, 35, 63)
	$D_4$	(5, 21, 45)	(5, 21, 45)	(35, 63, 81)	(9, 25, 49)
	$D_5$	(25, 49, 81)	(25, 49, 81)	(5, 21, 45)	(25, 49, 81)
Alternative $A_6$	$D_1$	(15, 35, 63)	(1, 9, 25)	(21, 45, 63)	(7, 27, 45)
	$D_2$	(35, 63, 81)	(15, 35, 63)	(35, 63, 81)	(3, 15, 35)
	$D_3$	(3, 15, 35)	(7, 27, 45)	(25, 49, 81)	(25, 49, 81)
	$D_4$	(1, 9, 25)	(25, 49, 81)	(21, 45, 63)	(3, 15, 35)
	$D_5$	(5, 21, 45)	(25, 49, 81)	(1, 9, 25)	(15, 21, 63)
Alternative $A_7$	$D_1$	(25, 49, 81)	(3, 15, 35)	(7, 27, 45)	(7, 27, 45)
	$D_2$	(35, 63, 81)	(35, 63, 81)	(21, 45, 63)	(15, 35, 63)
	$D_3$	(21, 45, 63)	(7, 27, 45)	(35, 63, 81)	(35, 63, 81)
	$D_4$	(3, 15, 35)	(25, 49, 81)	(7, 27, 45)	(15, 35, 63)
	$D_5$	(25, 49, 81)	(25, 49, 81)	(3, 15, 35)	(5, 21, 45)

To reflect on the decision makers' attitude towards risk in the decision making process, the idea of incorporating the risk involved in the decision makers' subjective assessments is introduced. In this case, the decision makers are assumed to share the same attitude towards

risk and they apply  $\lambda = 0.5$  to Table 11.3 by using (7.4). Table 11.4 shows the fuzzy performance matrix for individual decision makers.

**Table 11.4 The Fuzzy Performance Matrix for Individual Decision Makers**

	Decision	Criteria			
		$C_1$	$C_2$	$C_3$	$C_4$
Alternative $A_1$	$D_1$	(37, 49, 65)	(17, 27, 36)	(17, 27, 36)	(65, 81, 81)
	$D_2$	(33, 45, 54)	(49, 63, 72)	(33, 45, 54)	(25, 35, 49)
	$D_3$	(9, 15, 25)	(49, 63, 72)	(49, 63, 72)	(42, 49, 65)
	$D_4$	(9, 15, 25)	(25, 35, 49)	(49, 63, 72)	(17, 25, 37)
	$D_5$	(49, 63, 72)	(37, 49, 65)	(17, 27, 36)	(37, 49, 65)
Alternative $A_2$	$D_1$	(25, 35, 49)	(13, 21, 33)	(17, 27, 36)	(65, 81, 81)
	$D_2$	(65, 81, 81)	(37, 49, 65)	(17, 27, 36)	(33, 45, 54)
	$D_3$	(25, 35, 49)	(65, 81, 81)	(37, 49, 65)	(37, 49, 65)
	$D_4$	(17, 27, 36)	(37, 49, 65)	(49, 63, 72)	(25, 35, 49)
	$D_5$	(37, 49, 65)	(49, 63, 72)	(17, 27, 36)	(49, 63, 72)
Alternative $A_3$	$D_1$	(49, 63, 72)	(5, 9, 17)	(65, 81, 81)	(65, 81, 81)
	$D_2$	(33, 45, 54)	(37, 49, 65)	(17, 27, 36)	(25, 35, 49)
	$D_3$	(25, 35, 49)	(65, 81, 81)	(49, 63, 72)	(49, 63, 72)
	$D_4$	(13, 21, 33)	(13, 21, 33)	(17, 27, 36)	(9, 15, 25)
	$D_5$	(25, 35, 49)	(49, 63, 72)	(9, 15, 25)	(37, 49, 65)
Alternative $A_4$	$D_1$	(49, 63, 72)	(13, 21, 33)	(17, 27, 36)	(49, 63, 72)
	$D_2$	(49, 63, 72)	(37, 49, 65)	(65, 81, 81)	(33, 45, 54)
	$D_3$	(17, 25, 37)	(65, 81, 81)	(25, 35, 49)	(37, 49, 65)
	$D_4$	(13, 21, 33)	(37, 49, 65)	(49, 63, 72)	(25, 35, 49)
	$D_5$	(49, 63, 72)	(37, 49, 65)	(17, 27, 36)	(49, 63, 72)
Alternative $A_5$	$D_1$	(37, 49, 65)	(13, 21, 33)	(13, 21, 33)	(65, 81, 81)
	$D_2$	(33, 45, 54)	(37, 49, 65)	(33, 45, 54)	(25, 35, 49)
	$D_3$	(9, 15, 25)	(49, 63, 72)	(13, 21, 33)	(25, 35, 49)
	$D_4$	(13, 21, 33)	(13, 21, 33)	(49, 63, 72)	(17, 25, 37)
	$D_5$	(37, 49, 65)	(37, 49, 65)	(13, 21, 33)	(37, 49, 65)
Alternative $A_6$	$D_1$	(25, 35, 49)	(5, 9, 17)	(33, 45, 54)	(17, 27, 36)
	$D_2$	(49, 63, 72)	(25, 35, 49)	(49, 63, 72)	(9, 15, 25)
	$D_3$	(9, 15, 25)	(17, 27, 36)	(37, 49, 65)	(37, 49, 65)
	$D_4$	(5, 9, 17)	(37, 49, 65)	(33, 45, 54)	(9, 15, 25)
	$D_5$	(13, 21, 33)	(37, 49, 65)	(5, 9, 17)	(18, 21, 42)
Alternative $A_7$	$D_1$	(37, 49, 65)	(9, 15, 25)	(17, 27, 36)	(17, 27, 36)
	$D_2$	(49, 63, 72)	(49, 63, 72)	(33, 45, 54)	(25, 35, 49)
	$D_3$	(33, 45, 54)	(17, 27, 36)	(49, 63, 72)	(49, 63, 72)
	$D_4$	(9, 15, 25)	(37, 49, 65)	(17, 27, 36)	(25, 35, 49)
	$D_5$	(37, 49, 65)	(37, 49, 65)	(9, 15, 25)	(13, 21, 33)

By averaging the fuzzy assessments made by individual decision makers as given in (7.6), the overall fuzzy group performance matrix of hotel location alternatives can be obtained as in Table 11.5

**Table 11.5 The Overall Fuzzy Decision Matrix of Hotel Location Alternatives**

Alternatives	Criteria			
	$C_1$	$C_2$	$C_3$	$C_4$
$A_1$	(27.4, 37.4, 48.2)	(35.4, 47.4, 58.8)	(33, 45, 54)	(37.2, 47.8, 59.4)
$A_2$	(33.8, 45.4, 56)	(40.2, 52.6, 63.2)	(27.4, 38.6, 49)	(41.8, 54.6, 64.2)
$A_3$	(29, 39.8, 51.4)	(33.8, 44.6, 53.6)	(31.4, 42.6, 50)	(37, 48.6, 58.4)
$A_4$	(35.4, 47, 57.2)	(37.8, 49.8, 61.8)	(34.6, 46.6, 54.8)	(38.6, 51, 62.4)
$A_5$	(25.8, 35.8, 48.4)	(29.8, 40.6, 53.6)	(24.2, 34.2, 45)	(33.8, 45, 56.2)
$A_6$	(20.2, 28.6, 39.2)	(24.2, 33.8, 46.4)	(31.4, 42.2, 52.4)	(18, 25.4, 38.6)
$A_7$	(33, 44.2, 56.2)	(29.8, 40.6, 52.6)	(25, 35.4, 44.6)	(25.8, 36.2, 47.8)

From (7.7) to (7.18), the Hamming distance between each alternative and the positive ideal solution  $S_i^{\lambda+}$  and between the alternative and the negative ideal solution  $S_i^{\lambda-}$  can be calculated respectively. Table 11.6 shows the results.

**Table 11.6 The Hamming Distance Between Each Alternative and the Ideal Solutions**

$A_i$	$S_i^{\lambda+}$	$S_i^{\lambda-}$
$A_1$	0.31	1.48
$A_2$	0.34	1.21
$A_3$	1.78	2.46
$A_4$	1.46	2.71
$A_5$	0.63	0.66
$A_6$	1.28	0.91
$A_7$	0.29	0.73

The overall performance index value of each hotel location alternative across all the criteria can be obtained by applying (7.19) to the data in Table 11.6. Table 11.7 shows the overall performance index of the hotel location alternatives and their corresponding rankings with respect to the decision makers' attitudes towards risk.  $A_1$  is the most suitable hotel location for selection as it has the highest value of 0.83.

Further analysis can be conducted with the risk-oriented approach to explore the relationships between the ranking order of the hotel location alternatives and the decision makers' different attitudes toward risk by applying  $\lambda = 0.0$  and  $1.0$  respectively. The results obtained are consistent on whether the decision makers involved have an optimistic, moderate, or pessimistic view in the selection process, thus making the decision makers more confident about their choices in this evaluation and selection problem. Table 11.7 shows the relationships between the ranking order of the hotel location alternatives and the decision makers' attitudes towards risk.

**Table 11.7 The Overall Performance Index and Ranking of Hotel Location Alternatives**

Hotel Location Alternatives	$\lambda = 0.0$		$\lambda = 0.5$		$\lambda = 1.0$	
	Index	Ranking	Index	Ranking	Index	Ranking
$A_1$	0.81	1	0.83	1	0.84	1
$A_2$	0.74	2	0.78	2	0.75	2
$A_3$	0.56	5	0.58	5	0.57	5
$A_4$	0.63	4	0.65	4	0.63	4
$A_5$	0.49	6	0.51	6	0.51	6
$A_6$	0.41	7	0.42	7	0.43	7
$A_7$	0.71	3	0.72	3	0.70	3

With the simplicity in concept underlying the approach, this approach can be incorporated into a decision support system in which the decision makers can interactively explore the attitudes of the decision makers towards risk in different manners so that a better understanding of the problem and the relationships between the decision and its parameters can be obtained. This would give the decision makers much more confidence in making their selection decisions in real world settings.

The study suggests that the risk-oriented approach is simple and effective in dealing with the uncertain and imprecise nature of the evaluation process faced by multiple decision makers in the hotel location evaluation and selection problem. The risk-oriented approach provides an effective mechanism whereby the final decision outcome is directly linked to the decision maker's degree of confidence towards risk.

## **11.5 Concluding Remarks**

The hotel location evaluation and selection process is challenging due to the presence of subjectiveness and imprecision inherent in the human decision making process. The existence of subjectiveness and imprecision is because it is common for the decision makers to make subjective assessments with respect to the criteria importance and the performance rating with respect to each criterion in the decision making process. To effectively solve this problem, this chapter has formulated the hotel location evaluation and selection problem as a multicriteria group decision making problem and applied the risk-oriented approach developed in Chapter 7 to address the evaluation and selection problem.

The result shows that the risk-oriented approach applied to solve the hotel location evaluation and selection problem provides an effective and useful way to deal with fuzzy multicriteria group decision making problems as it is capable of incorporating the risk inherent in the hotel location evaluation and selection process. The approach is found to be effective and efficient, due to the comprehensibility of its underlying concepts and the straightforward computation process.

# Chapter 12

## Conclusion

### 12.1 Introduction

Tremendous efforts have been spent and significant advances have been made towards the development of various fuzzy multicriteria analysis approaches for solving various multicriteria decision making problems. However, there is no best approach for solving the general multicriteria decision making problem. This is because most existing approaches suffer from various shortcomings including (a) the failure to adequately handle the subjectiveness and imprecision inherent in the evaluation process (Deng and Wibowo, 2008), (b) the requirement of a complicated mathematical computation (Lee and Kim, 2001; Gabriel et al., 2005), and (c) the failure to adequately handle the various requirements of the decision maker(s) (Yeh et al., 2010). It is obvious that the development of simple, comprehensible and efficient approaches, which are capable of addressing the various shortcomings of existing approaches, is desirable.

This study has developed four novel approaches for efficiently and effectively solving fuzzy multicriteria decision making problems involving a single decision maker or multiple decision makers. Four decision contexts for the fuzzy multicriteria decision making problem have been identified. The results show that these approaches are capable of effectively solving the multicriteria decision making problem under uncertainty with respect to specific characteristics of the problem in a simple and consistent manner.



The purpose of this chapter is to present a summary of the developments and their applications for solving practical fuzzy multicriteria decision making problems. The characteristics of individual approaches developed are illustrated, and the implications of the empirical studies in relation to the application of the four developed approaches for addressing real fuzzy multicriteria decision making problems are explained for showing the applicability of these approaches for handling the fuzzy multicriteria decision making problem in real situations. The specific contributions of this study and some suggestions for future research are discussed.

## **12.2 Characteristics of the Approaches Developed**

The fundamental motivation for the development of new methodologies in fuzzy multicriteria decision making problem is the desire to (a) adequately handle the subjectiveness and imprecision inherent in the human decision making process, (b) avoid the requirement of complicated mathematical computation, and (c) effectively reduce the cognitively demand on the decision maker(s) (Pohekar and Ramachandran, 2004; Deng, 2005; Kahraman, 2008). Despite the development of various fuzzy multicriteria analysis approaches for solving various multicriteria decision making problems, most existing multicriteria analysis approaches suffer from various shortcomings including (a) the requirement of complicated mathematical programming, (b) the inadequacy to tackle the subjectiveness and imprecision present in the evaluation process, (c) the unreliability and complexity of the ranking procedures in comparing the utility values, and (d) the inconsistency of ranking outcomes.

To address the shortcomings of the existing approaches, this study has developed four novel approaches for solving the fuzzy multicriteria decision making problem in a simple and effective manner. Linguistic terms approximated by fuzzy numbers are used to formulate the fuzzy multicriteria decision making problem in a cognitively less demanding manner for better handling the subjectiveness and imprecision inherent in the fuzzy multicriteria decision making process. As a result, effective decisions can be made.

Chapter 4 has developed a pairwise comparison based approach to help reduce the cognitive demanding on the decision maker in the multicriteria decision making problem. To effectively model the inherent subjectiveness and imprecision of the human decision making process, linguistic variables approximated by fuzzy numbers are used. To greatly reduce the decision maker's cognitive burden in the evaluation process, the pairwise comparison technique is adopted. To avoid the complicated and unreliable process of comparing and ranking fuzzy utilities, the concept of the degree of dominance between alternatives is introduced for calculating an overall performance index for every alternative across all criteria. As a result, effective evaluation and selection decisions can be made due to the great reduction of the cognitive demanding on the decision maker and the adequate modelling of the subjectiveness and imprecision in the decision making process.

To adequately meet the interest of various stakeholders in the multicriteria decision making process, Chapter 5 has presented a decision support system (DSS) based approach for effectively solving the multicriteria group decision making problem in which both the criteria importance and alternative performance are presented subjectively by multiple decision makers. To avoid the complex and unreliable process of comparing fuzzy numbers usually required in fuzzy multicriteria analysis (Shih et al., 2005), a new algorithm is developed

based on the degree of dominance (Deng, 1999) and the degree of optimality (Yeh et al., 2000). A DSS is introduced to facilitate the multicriteria group decision making process efficiently and effectively. This leads to effective decisions being made in the multicriteria group decision making problem.

To effectively improve the acceptance of the decision made by multiple decision makers, a consensus based approach for multicriteria group decision making is developed in Chapter 6. A consensus building algorithm is developed for solving the multicriteria group decision making problem. To facilitate its use in solving real world decision making problems, a DSS is proposed incorporating the proposed consensus building algorithm for facilitating the consensus building process in solving the multicriteria group decision making problem. This consensus based approach is capable of effectively and efficiently handling the group decision making process in the multicriteria group decision making problem.

To effectively explore the risk inherent in the multicriteria decision making process, a risk-oriented approach for multicriteria group decision making is developed in Chapter 7. Linguistic variables approximated by triangular fuzzy numbers are used for representing the uncertain and imprecise assessments of the decision makers in evaluating the relative importance of the evaluation criteria and the performance of alternatives. The concept based on  $\lambda$  ( $0 \leq \lambda \leq 1$ ) is introduced for reflecting the decision makers' attitude towards risk in approximating their subjective assessments. The concept of ideal solutions is applied for calculating the overall performance index for each alternative across all criteria so that the complex and unreliable process of comparing fuzzy utilities is avoided.

## **12.3 Implications of the Empirical Studies**

The empirical studies of four real fuzzy multicriteria decision making problems have been presented in this research for demonstrating the applicability of the four novel approaches developed in solving practical fuzzy multicriteria decision making problems. These studies show that the four novel approaches developed are effective and efficient for solving the fuzzy multicriteria decision making problem in a simple and straightforward manner.

Chapter 8 has presented an empirical study on a hospital location evaluation and selection problem in Taiwan to exemplify applicability of the pairwise comparison based approach developed for effectively solving the hospital location selection problem. Two common issues are involved in this evaluation process. The evaluation criteria are generally multi-dimensional in nature and a simultaneous consideration of those multiple criteria is required for making effective decisions. The evaluation process involves subjective assessments, resulting in qualitative and vague data being used.

To facilitate the subjective evaluation process, linguistic variables are used for representing the subjective assessments of the decision maker. To ensure the efficiency of the computation process for making the selection decision, fuzzy numbers are used to approximate the linguistic variables in the evaluation process. The pairwise comparison based approach is found to be effective and efficient, due to the comprehensibility of its underlying concepts and the straightforward computation process.

Chapter 9 has presented an empirical study of an international distribution centre evaluation and selection problem to exemplify the applicability of the DSS based approach for solving

the real multicriteria evaluation and selection problem under uncertainty. The international distribution centre evaluation and selection process involves the presence of multiple decision makers, numerous selection criteria, and subjectiveness and imprecision inherent in the human decision making process. The existence of subjectiveness and imprecision is because it is common for the decision makers to make subjective assessments with respect to the criteria importance and the international distribution centre's performance with respect to each criterion in the problem solving process.

The study reveals that the DSS based approach applied to solve the international distribution centre evaluation and selection problem is capable of adequately handling the subjectiveness and imprecision inherent in the international distribution centre evaluation and selection process. The DSS approach is found to be effective and efficient, due to the comprehensibility of its underlying concepts and the straightforward computation process. In particular, the use of this approach greatly reduces the decision makers' cognitive burden in the decision making process and further improves the consistency of the decision makers' decisions.

In Chapter 10, the application of a consensus based approach for addressing a supplier evaluation and selection problem is presented. This is to exemplify the applicability of the consensus based approach for dealing with the uncertain and imprecise nature of the evaluation process faced by decision makers in the supplier evaluation and selection process. In addition to the complex issue associated with the supplier evaluation and selection problem, it is critical to reach a certain level of agreement among the decision makers in selecting suppliers for facilitating the acceptance of the decision made.

It is shown that the consensus based approach is capable for (a) effectively handling the multi-dimensional nature of the selection process and the presence of subjectiveness and imprecision in supplier evaluation and selection problem, (b) reducing the cognitively demanding nature of the evaluation and selection process on the decision makers, and (c) considering the interest of different decision makers through consensus building in the evaluation and selection process. The merit of this approach includes its simplicity in concept and the efficiency in computation.

Chapter 11 has presented an empirical study of hotel location evaluation and selection problem to exemplify the applicability of the risk-oriented approach for solving the real multicriteria group evaluation and selection problem. The challenge of evaluating and selecting the most suitable hotel location comes from two perspectives: (a) the involvement of multiple decision makers in the decision making process and (b) the need for an appropriate consideration of the potential risk due to the subjectiveness and imprecision existent in the human decision making process. To ensure effective decision outcomes of the hotel location selection being made, it is important to adequately consider the potential risk in a specific decision making situation.

The result shows that the risk-oriented approach applied to solve the hotel location evaluation and selection problem is capable of adequately modelling the inherent risk in the multicriteria group decision making process and helping reduce the cognitively demanding nature of the evaluation and selection process on the decision makers. The approach is found to be effective and efficient, due to the comprehensibility of its underlying concepts and the straightforward computation process.

## 12.4 Contributions of the Research

This study has comprehensively reviewed existing multicriteria analysis approaches. This literature review is organized from the perspectives of (a) multicriteria decision making with a single decision maker and (b) multicriteria group decision making. Multicriteria decision making approaches with a single decision maker can be classified into (a) utility based approaches, (b) mathematical programming approaches, (c) pairwise comparison based approaches, and (d) outranking approaches. Multicriteria group decision making approaches can be classified into (a) majority based approaches, (b) ranking based approaches, and (c) consensus based approaches.

A comparative analysis of existing approaches to multicriteria decision making demonstrates the merits of individual approaches for addressing real multicriteria decision making problems under various circumstances. Such an analysis also shows that existing approaches are not totally satisfactory for effectively solving the multicriteria decision making problem. Most existing multicriteria analysis approaches suffer from various shortcomings including (a) the requirement of complicated mathematical programming, (b) the inability to handle the subjectiveness and imprecision present in the evaluation process, (c) the unreliability and complexity of the ranking procedures in comparing the utility values, and (d) the inconsistency of ranking outcomes.

The contributions of this research are mainly from two perspectives. The first main contribution is the development of four novel approaches for solving the multicriteria decision making problem under uncertainty involving a single decision maker and multiple decision makers in a given situation. The second main contribution is the presentation of four

empirical studies for demonstrating the applicability of the four novel approaches developed in solving real multicriteria decision making problems under uncertainty.

Recognizing the cognitively demanding nature of the decision making process on the decision maker and the presence of inherent subjectiveness and imprecision of the human decision making process, a pairwise comparison based approach for adequately solving the multicriteria problem under uncertainty is developed in Chapter 4.

To adequately meet the interest of various stakeholders in the multicriteria decision making process, a DSS based approach is introduced in Chapter 5 for effectively solving the multicriteria group decision making problem. As a result, effective decisions can be made due to the adequate modelling of the uncertainty in the decision making process and the reduction of the cognitive demanding on the decision makers.

Chapter 6 presents a consensus based approach for effectively solving the multicriteria group decision making problem. To facilitate its use in solving real world decision making problems, a DSS is proposed incorporating the proposed consensus building algorithm for facilitating the consensus building process in solving the multicriteria group decision making problem.

Chapter 7 presents a risk-oriented approach for adequately modelling the inherent risk in the multicriteria group decision making process. Linguistic variables approximated by triangular fuzzy numbers are used for representing the subjective and imprecise assessments of the decision maker in evaluating the relative importance of the evaluation criteria and the performance of alternatives. The concept of ideal solutions is applied for calculating the



overall performance index for each alternative across all criteria so that the complex and unreliable process of comparing fuzzy utilities is avoided.

The second main contribution of this research is the presentation of four empirical studies on the application of the four novel approaches developed for solving four real multicriteria decision making problems under uncertainty. Such empirical studies help illustrate the applicability of the four novel approaches developed for solving the general fuzzy multicriteria decision making problem. Each of the multicriteria decision making problems has different requirements and characteristics, thus requiring a specific approach for dealing with each problem differently. The studies show that the four novel approaches developed are capable of solving practical multicriteria decision making problems under uncertainty efficiently and effectively.

## **12.5 Suggestions for Future Research**

Multicriteria decision making continues to be an important decision making problem for modern organizations in today's complex and competitive environment. The challenge of evaluating and selecting the most appropriate alternative comes from the need to (a) adequately handle the subjectiveness and imprecision inherent in the decision making process, and (b) make transparent and balanced selection decisions based on a comprehensive evaluation of all available alternatives in a timely manner. The study conducted in this research only covers part of the multicriteria decision making areas. There are a few other areas that can be explored further including:

- (a) A comprehensive comparative study between existing fuzzy multicriteria analysis approaches is desirable. This is particularly relevant for situations where various means are used to calculate the overall performance index for each alternative across all criteria in order to avoid the unreliable and cumbersome ranking process for comparing fuzzy utilities.
- (b) Extensions of existing multicriteria analysis approaches to deal with group decision making situations, in particular when fuzzy assessments are involved in the presence of multiple decision makers. The development of fuzzy consensus building process in multicriteria group decision making problem is of practical significance in real situations.
- (c) The development of a DSS, incorporating other computing approaches such as neural networks and genetic algorithms for providing effective mechanisms in modelling the decision maker's preference and to effectively handle the inherent uncertainty, imprecision and vagueness of the human decision making process in a fuzzy environment.

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# Appendix A

## List of Abbreviations

AHP	Analytical hierarchy process
ANP	Analytical network process
AWA	Additive weighted aggregation
OWA	Ordered weighted averaging
CI	Consistency index
DSS	Decision support systems
ELECTRE	Elimination and et choice translation reality
MAH	Maximize agreement heuristic
MAUT	Multiattribute utility theory
PROMETHEE	Preference ranking organization method for enrichment evaluation
SAW	Simple additive weighting
SMART	Simple multiattribute rating technique
TFT-LCD	Thin film transistor liquid crystal display
TOPSIS	Technique for order preference by similarity to ideal solution